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NATO ARMY ARMAMENTS GROUP
LAND GROUP 1 ON INTEROPERABILITY OF LAND COMMAND AND CONTROL INFORMATION SYSTEMS ON THE DIGITISED BATTLEFIELD
LAND GROUP 2 ON CLOSE COMBAT - ARMOUR
LAND GROUP 3 ON CLOSE COMBAT - INFANTRY
LAND GROUP 4 ON SURFACE-TO-SURFACE ARTILLERY
LAND GROUP 5 ON ARMY AIR DEFENCE
LAND GROUP 6 ON SURVEILLANCE, TARGET ACQUISITION, NIGHT OBSERVATION, COUNTERSURVEILLANCE AND ELECTRONIC WARFARE (STANOC AND EW)
LAND GROUP 7 ON JOINT NBC DEFENCE
LAND GROUP 8 ON SIMULATION INTEROPERABILITY FOR JOINT TRAINING AND OPERATIONAL SUPPORT
LAND GROUP 9 ON BATTLEFIELD ENGINEERING
LAND GROUP 10 ON BATTLEFIELD HELICOPTERS

Land Operations in the Year 2020 (LO2020)

Note by the Head, Land Armaments Section

1. Please find attached a copy of the Research and Technology Organisation study - Land Operations 2020. The report has not yet been translated into French. Once available, it too will be distributed under cover of an AC/225 document.

2. The NAAG has tasked all Land Groups to review the study and include in their 2000 Annual Reports an assessment of the implications of this study on their work.

(Signed) R. FROH

Enclosures: 1

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NORTH ATLANTIC TREATY ORGANIZATION

RESEARCH AND TECHNOLOGY ORGANIZATION

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RTO TECHNICAL REPORT 8

Land Operations in the Year 2020 (LO2020)

(Opérations terrestres à l'horizon 2020 (LO2020))

This study was carried out at the request of SHAPE (Supreme Headquarters Allied Powers Europe), and was managed by the Studies, Analysis and Simulation Panel (SAS).

Published March 1999

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The Research and Technology Organization (RTO) of NATO

RTO is the single focus in NATO for Defence Research and Technology activities. Its mission is to conduct and promote cooperative research and information exchange. The objective is to support the development and effective use of national defence research and technology and to meet the military needs of the Alliance, to maintain a technological lead, and to provide advice to NATO and national decision makers. The RTO performs its mission with the support of an extensive network of national experts. It also ensures effective coordination with other NATO bodies involved in R&T activities.

RTO reports both to the Military Committee of NATO and to the Conference of National Armament Directors. It comprises a Research and Technology Board (RTB) as the highest level of national representation and the Research and Technology Agency (RTA), a dedicated staff with its headquarters in Neuilly, near Paris, France. In order to facilitate contacts with the military users and other NATO activities, a small part of the RTA staff is located in NATO Headquarters in Brussels. The Brussels staff also coordinates RTO's cooperation with nations in Middle and Eastern Europe, to which RTO attaches particular importance especially as working together in the field of research is one of the more promising areas of initial cooperation.

The total spectrum of R&T activities is covered by 6 Panels, dealing with:

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- SET Sensors and Electronics Technology
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- AVT Applied Vehicle Technology
- HFM Human Factors and Medicine

These Panels are made up of national representatives as well as generally recognised 'world class' scientists. The Panels also provide a communication link to military users and other NATO bodies. RTO's scientific and technological work is carried out by Technical Teams, created for specific activities and with a specific duration. Such Technical Teams can organise workshops, symposia, field trials, lecture series and training courses. An important function of these Technical Teams is to ensure the continuity of the expert networks.

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Land Operations in the Year 2020 (LO2020)

(RTO TR-8)

Executive Summary

This study, which was requested by SHAPE, identifies the most critical key and emerging technologies and the impact they will have on military land forces in the year 2020. It also addresses the likely nature of the battlefield, the types of land forces, and their characteristics and capabilities. This will help NATO plan its research and development, and SHAPE will use it as input to the NATO Defence Planning Process.

Main Conclusions

Although there will be a wide range of demands on NATO forces in 2020, the highest priority is the ability to fight a full-scale conflict. War-fighting must remain the basic ethos, but with the ability to adapt to other types of operation. Enhanced protection against the full spectrum of attacks must be incorporated into NATO doctrine and force structure.

The battle space in 2020 will be variable in density, non-linear, and more dispersed. It will be cellular in nature, multi-directional and increasingly determined by what is above the battlefield in air and space. The most demanding, yet probable, environment for conflict is likely to be urban.

Interoperability will continue to pose a challenge as NATO incorporates new members. Harmonisation of doctrine, information systems, and communications is essential.

Information dominance and superiority will remain a key military objective.

Reduction in logistic drag will be essential for effective military operations in 2020.

Impact of Technology

Force structures will need to change in order to exploit technology to the fullest.

The following broad technology areas are deemed to be of special importance:

> High Power Electrical Technologies, Directed Energy Weapons, Computing Technologies, Communication Technologies, Electronic/Information Warfare Technologies, Electronic Devices, Biotechnology, Structural Materials Technologies, Human Factors and Man-Machine Interfaces, Precision Attack Technologies, and Automation and Robotics.

Each of these areas is underpinned by a large number of basic technologies. Four key emerging technology areas were identified for further research projects:

> High Power Battlefield Electrical Systems, Biotechnology, Micro Electrical-Mechanical Systems (MEMS), and Novel Energetic Materials.

Several emerging technology applications were also identified:

> Precision Attack, Sensing, Information Fusion, Digitisation, Non-Lethal Weapons and Barriers, Robotics, Simulation and Synthetic Environments, and Modular Systems.

Advances in these areas will contribute to tempo, sustainability, manoeuvre, protection, interoperability, acquisition, force structure, and soldier systems – all the major military requirement areas identified in the study.

Major Recommendations

- NATO should provide the focus for the development of key technologies with special emphasis on standardisation and interoperability between member nations.
- The NATO Research and Technology Organisation should initiate studies or collaborative research programmes on the most promising emerging technologies.
- SHAPE should consider the conclusions and recommendations of this study for inclusion in the 2000 Defence Planning Cycle.
- SHAPE should establish a NATO military working group to study joint and combined concepts and doctrine.

A fuller overview follows the contents list.

Opérations terrestres à l'horizon 2020 (LO2020)

(RTO TR-8)

Synthèse

Cette étude, qui a été réalisée à la demande du SHAPE, identifie les technologies clés et naissantes les plus importantes et leur impact sur les forces militaires terrestres à l'horizon 2020. Elle examine également la nature probable du champ de bataille, les types de forces terrestres, leurs caractéristiques et capacités. Elle sera d'une grande utilité pour la planification des activités de recherche et développement de l'OTAN et servira au SHAPE dans le cadre de sa contribution aux Procédures de planification de la défense de l'OTAN.

Conclusions principales

Vraisemblablement, les forces de l'OTAN seront appelées à réaliser des interventions très diverses d'ici l'an 2020, mais la priorité numéro un demeurera la capacité de livrer une bataille de grande envergure. La conduite de la guerre doit subsister en tant que ligne directrice, mais avec la possibilité d'adaptation à d'autres types d'opérations. La protection renforcée contre l'éventail complet d'attaques possibles doit être incorporée dans la structure des forces de l'OTAN, ainsi que dans sa doctrine.

L'espace de bataille de l'an 2020 sera variable en densité, non-linéaire et plus dispersé. Il sera de nature cellulaire, multidirectionnelle, et de plus en plus déterminé par les éléments aériens et spatiaux se trouvant au-dessus du champ de bataille. L'environnement urbain sera l'environnement de conflit le plus difficile, mais en même temps le plus probable.

L'interopérabilité continuera de poser des problèmes avec l'élargissement de l'OTAN. L'harmonisation des doctrines, et des systèmes d'information et communications est essentielle.

La domination de l'information et la supériorité demeureront un objectif militaire clé.

La diminution des délais d'acheminement de la logistique sera indispensable à la réussite des opérations militaires en l'an 2020.

L'impact des technologies

Il faudra procéder à des changements au niveau des structures des forces afin de profiter au maximum des nouvelles technologies.

Les grands domaines technologiques suivants sont jugés d'une importance particulière :

> Les technologies électriques à grande puissance, les armes à énergie dirigée, les technologies de l'informatique, les technologies des télécommunications, les technologies électronique/de la guerre de l'information, les dispositifs électroniques, la biotechnologie, les technologies des structures et matériaux, les facteurs humains et les interfaces homme-machine, les technologies d'attaque de précision, l'automatisation et la robotique.

Chacun de ces domaines est soutenu par un grand nombre de technologies de base. Quatre nouveaux domaines technologiques clés ont été désignés pour de futurs projets de recherche :

> Les systèmes électriques militaires de grande puissance, la biotechnologie, les systèmes microélectriques-mécaniques (MEMS) et les matériaux énergétiques novateurs.

Un certain nombre de nouvelles applications technologiques ont également été identifiées :

attaque de précision, télédétection, fusion des données, numérisation, armes non-létales et barrières, robotique, simulation et environnements synthétiques et systèmes modulaires.

Les progrès réalisés dans ces domaines apporteront leur contribution au rythme des opérations, au soutien des forces, à la manoeuvre, à la protection, à l'interopérabilité, aux approvisionnements, à la structure des forces et aux systèmes d'infanterie – en somme, à l'ensemble des grands domaines militaires identifiés par cette étude.

Recommandations principales

- L'OTAN doit être le point de convergence pour le développement des technologies clés en privilégiant la standardisation et l'interopérabilité entre pays membres.
- L'Organisation pour la recherche et la technologie de l'OTAN doit lancer des études et des projets de recherche en coopération sur les technologies naissantes les plus prometteuses.
- Le SHAPE doit réfléchir à la possibilité d'inclure les conclusions et les recommandations de cette étude dans le cycle de planification de la défense à l'horizon 2000.
- Le SHAPE doit établir un groupe de travail militaire OTAN pour étudier des concepts et des doctrines interarmées multinationaux.

La table des matières est suivie d'une synthèse plus complète.

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List of Tables and Figures

Glossary of Acronyms and Terms

AAN	Army After Next
AD	Air Defence
ADC	Analog to Digital Converter
AFV	Armoured Fighting Vehicle
AH	Attack Helicopter
AHP	Analytical Hierarchy Process
AI	Artificial Intelligence
AIGaAs	Aluminium Gallium Arsenide
ANOVA	Analysis of Variance
AO	Adaptive Optics
APOD	Air Port of Disembarkation
APS	Active Protection System
AS90	155mm Artillery System
ASIC	Application Specific Integrated Circuits
ASTOR	Airborne Stand-Off Radar
ATGW	Anti-Tank Guided Weapons
ATM	Asynchronous Transfer Mode
BDA	Battle Damage Assessment
BDR	Battle Damage Repair
BLING	Bladed Ring
BLOS	Beyond-line of sight
C2I	Command, Control and Intelligence
C2W	Command and Control Warfare
C3	Command, Control and Communications
C3I	Command, Control, Communications and Intelligence
C4I	Command, Control, Communications, Computers, and Intelligence
CARM	Cyclotron Autoresonant Maser
CB	Chemical and Biological
CCD	Charge Coupled Device
CDA	Centre for Defence Analysis
CDAS	Counter Defensive Aid Suit
CDMA	Code Division Multiple Access
CIFF	Combat Identification Friend or Foe
CIS	Combat Information System
CIS	Command and Information System
CLOS	Command to Line of Sight
CMC	Ceramic Metal Composite
COLPRO	Collective Protection
COTS	Commercial off the Shelf
CRITECH	Critical Technology (exercise)
CTBW	Chemical, Toxin, and Biological Warfare
CW	Continuous-wave
DAC	Digital to Analog converter
DARPA	Defence Advanced Research Projects Agency
DAS	Defensive Aids Suit
DBMS	Database Management Systems
DERA	Defence Evaluation and Research Agency
DEW	Directed Energy Weapon
DF	Deuterium Fluoride
DLW	Directorate of Land Warfare
DMP	Defence Materiel Procurement
DNA	DeoxyriboNucleic Acid
DRG	Defence Research Group

DRR 99	Defence Requirements Review 1999
DRR	Defence Requirements Review
DSP	Digital Signal Processing
DU	Depleted Uranium
ECCM	Electro Counter-Counter-Measures
ECM	Electro Counter-Measures
EHF	Extremely High Frequency
EM	Electro Magnetic
EMC	Electro Magnetic Compatibility
EMI	Electromagnetic Interference
EMP	Electro Magnetic Pulse
EMS	Electro Magnetic Spectrum
EO	Electro Optic
EOD	Explosive Ordnance Disposal
ERA	Explosive Reactive Armour
ESD	Electrostatic Damage
ETC	Electro Thermal Chemical
EW	Electronic Warfare
Fe:InP	Iron: Indium Phosphide
FEL	Free Electron Lasers
FET	Field Effect Transistors
FIST	Future Infantry Soldier Technologies
FLIR	Forward Looking Infrared
FOG(M)	Fibre Optic Guided Munitions
FSED	Full Scale Engineering Development
FSS	Frequency Selecting Surfaces
FWM	Four-wave Mixing
GaAIAs	Gallium Aluminium Arsenide
GaAs	Gallium Arsenide
GaN	Gallium Nitride
GaP	Gallium Phosphide
GPS	Global Positioning System
GW	Giga-watt
HF	Hydrogen Fluoride
HPM	High-power Microwave
HTS	High Temperature Superconductors
HTSc	High Temperature Superconductivity
HUMINT	Human Intelligence
HUMS	Health and Usage Monitoring System
IEW	Information Electronic Warfare
IFF	Identification Friend or Foe
IHPTET	Integrated High Performance Turbine Engine Technology
InGaAsP	Indium Gallium Arsenide Phosphide
InGaN	Indium Gallium Nitride
InP	Indium Phosphide
InSb	Indium Antimonide
IPE	Individual Protection Equipment
IR	Infrared
IREB	Intense Relativistic Electron Beam
ISDN	Integrated Services Digital Network
ISO	International Standards Organisation
ISTAR	Intelligence, Surveillance, Target Acquisition and Reconnaissance
IT	Information Technology
KBS	Knowledge Based System
KE	Kinetic Energy
LADAR	Laser Radar
LAN	Local Area Network
LAW	Light Anti-Armour Weapon

LCD	Liquid Crystal Displays
LED	Light Emitting Diodes
LIDAR	Light Intensified Radar
LO	Land Operations
LO2020	Land Operations in the year 2020
LS	Land Systems
LTSS	Long Term Scientific Study
MBT	Main Battle Task
MDSS	Multi-Domain Smart Sensor
MEMS	Micro Electro Mechanical System
MILO	Magnetically Insulated Line Oscillator
MIPS	Million instructions per second
MLRS	Multiple Launch Rocket System
MLS	Multi Level Security
Mm/IR	Millimetre wave/Infrared
MMC	Metal Matric Composite
MMI	Man Machine Interface
MMIC	Monolithic Microwave Integrated Circuits
MMW	Millimetre wave
MNE	Multi-National Exercise
MO2015	Maritime Operations 2015
MOD	Ministry of Defence
MPM	Medium Power Microwave
MSG	Military Steering Group
MTI	Moving Target Indicator
NATO	North Atlantic Treaty Organisation
NBC	Nuclear Biological and Chemical
NCTR	Non Co-operative Target Recognition
Nd	Neodymium
NIS	NATO Information System
NLOS	Non Line Of Sight
NLW	Non Lethal Weapons
NQR	Nuclear Quadruple Resonance
NRT	Near Real Time
OA	Operational Analysis
OOTW	Operations Other Than War
OPO	Optical Parametric Oscillators
OPSEC	Operational Security
OPSS	Optically Activated Semiconductor Switches
ORBATS	Order of Battle
OTC	Officer in Tactical Command
OTM	On the Move
PCR	Polymerase Chain Reaction
PfP	Partnership for Peace
PHEMT	High Electron Mobility Transistors
PLD	Programmable Logic Devices
PLL	Phase Locked Loop
PLZT	Lead-Ianthanum-zirconium-titanate
PMC	Polymer Matrix Composite
PSO	Peace Support Operation
PZT	Lead-zirconium-titanate
QPM	Quasi Phase Matching
R&D	Research and Development
RADAR	Radio Detecting and Ranging
RAM	Radar Absorbent Materials
RAM-D	Reliability and Maintainability
RFDE	Radio Frequency Directed Energy
RF	Radio Frequency

RIF	Radar Information Fields
RISTA	Reconnaissance, Intelligence, Surveillance and Target Acquisition
RMA	Revolution in Military Affairs
RTB	Research and Technology Board
SADARM	Sense and Destroy Armour
SAR	Synthetic Aperture Radar
SAS	Studies, Analysis and Simulation
SATCOM	Satellite Communications
SBA	Simulation Based Acquisition
SBS	Stimulated Brillouin Scattering
SET	Single Electron Transistor
SFM	Sensor Fused Munitions
SFQ	Single Flux Quantum Logic
SHAPE	Supreme Headquarters Allied Powers Europe
Si	Silicon
SIA	Semiconductor Industry Associations
SiC	Silicon Carbide
SiGe	Silicon Germanium
SOI	Silicon-on-insulator
SPOD	Sea Port of Disembarkation
SQUID	Superconducting quantum interference device
STA	Surveillance Target Acquisition
STOW	Synthetic Theatre of War
T/R	Transmit/Receive
TGSM	Terminally Guided Sub-Munition
TRACER	British Armoured Scout Vehicle
TSG	Technical Study Group
TSW	Technology Seminar Wargame
TWT	Travelling wave Tube
UAV	Unmanned Aerial Vehicle
UGV	Unmanned Ground Vehicle
UMA	Unmanned Aircraft
UN	United Nations
UV	Ultra Violet
UWB	Ultra Wide Band
VHR	Very High Risk
VLR	Very Low Risk
VLSI	Very Large Scale Integration
WAN	Wide Area Network
WEU	Western European Union
WHA	Tungsten heavy alloys
WMD	Weapons of Mass Destruction
WST	Wafer Scale Technology
YAG	Yttrium Aluminium Garnet
ZnSe	Zinc Selenium

1. CHAPTER 1 - INTRODUCTION

1.1 INTRODUCTION

1.1.1 Purpose

The purpose of Long-Term Scientific Study 49 on Land Operations in the Year 2020 (LO2020) is to identify the types of land forces and their capabilities and characteristics that will be required on the NATO Battlefield in the year 2020 for warfighting and other military operations. This information will provide SHAPE, and subsequently the major NATO Commanders, with a basis for long-term requirements and defence planning guidance.

The study accomplished its aim by considering the availability and impact of new technologies that have the potential to appear in fielded weapon systems in the 2020 timeframe. The specific objectives of the study were to:

- identify and describe the likely nature of the battlefield in 2020,
- identify the types of land forces NATO needs in 2020,
- identify the required capabilities and characteristics of future land forces,
- assess the impact of technology on future battlefields and the desired characteristics for NATO Forces in 2020,
- recommend directions for Allied and national research and development to support land operations, and
- provide inputs to the Defence Requirements Review (DRR) and Force Goal Cycle.

1.1.2 Study Methodology

In the armaments development process *requirements* pull technology to develop weapon systems and *technology* pushes requirements to specify more capable weapon systems. With this in mind the LO2020 study was organised into two groups, a Military Steering Group (MSG) and a Technical Study Group (TSG). The study used a two-directional approach during the initial phase. The MSG provided a battlefield picture that defined the requirements for forces and their capabilities and characteristics. Concurrently, the TSG developed a list of technologies believed to have the highest potential for military applications and a description of potential specific uses and benefits. During the final portion of the study, the two groups combined into a single study group to complete the work.

<u>Phase 0 - Study Initiative</u>. An initial survey was carried out to determine the content, management, time scales, and resource requirements; and a Terms of Reference for the conduct for the LO2020 Study was written and approved. Initially, seven nations participated -- Canada, Denmark, France, Germany, The Netherlands, United Kingdom, and United States. Turkey joined the study in March 1998 and Greece joined in June 1998.

<u>Phase I – Search</u>. During Phase I the MSG and TSG functioned along two parallel paths. The MSG produced three documents to define the requirements

and assist the TSG in identifying technologies --

(a) Nature of the Battlefield (Annex 1),

(b) Force Description (Annex 2), and

(c) The Derivation of Capability Requirements from the Nature of the Battlefield (Annex 3).

The TSG produced a technology list using both top-down and bottom-up approaches. The TSG also identified and described the underpinning technologies needed to support higher level system development (Annex 4).

Phase II – Integration. In November 1997 the MSG and TSG were combined into a single study group. The study group conducted a Critical Technology Exercise to identify the most significant technologies based on military effectiveness, feasibility, and cost (Annex 5). Next, future weapon systems were proposed using the critical technologies to meet the requirements specified by the MSG. These proposed weapon systems were "fought" in a Technology Seminar Wargame (Annex 6) to identify the most significant weapon systems and thus, the technologies required to build the weapon systems were identified.

During this phase, the Maritime Operations 2015 (Annex 7) and Aerospace Operations 2020 (Annex 8) studies were reviewed to identify results of value to the Land Operations 2020 study.

A key effort during this phase was matching technological opportunities with the required force capabilities and characteristics that are not optimally satisfied by technologies currently in hand. Characteristics, such as likely maturity to be ready for engineering development in 2010, anticipated cost, and the scope of application, were addressed. A list of emerging technologies that satisfies the force capabilities and characteristics was produced using the expert opinions of both scientists and military operational specialists. An Initial Report was written and delivered to the Studies, Analysis and Simulation (SAS) Panel midway through Phase II.

Phase III – Review and Analysis. This phase included the review of all relevant documents developed during the course of Phases I and II leading up to the Multi-National Exercise and Final Report. A Working Paper was written to present the results of Phase I and II and to stimulate discussion during the Multi-National Exercise leading to completion of the Final Report.

1.2 ASSUMPTIONS

The study used the conservative assumption that no major technological breakthroughs will occur before the year 2020. The technologies considered in the study are well known and currently under development or part of a research effort.

The engineering application of each technology identified in the study is assumed to be sufficiently mature to produce and field a weapon system by the year 2020. Expert opinion was used to eliminate technologies that were not expected to be sufficiently mature by 2010 such that a fielded weapon system could be produced

and delivered by 2020. In practical terms, the study concentrated on emerging technologies that will be mature enough for engineering development by the year 2010.

It was assumed that robust logistic support will be available in 2020 to support the weapon systems identified and will be developed concurrently with the weapon systems. Logistics issues were not a direct consideration of this study.

Continued progress toward total battlefield digitisation with the resulting availability of a mature information infrastructure in 2020 was assumed. The technologies needed to produce and field a digitised infrastructure were identified and considered during the Critical Technology Exercise. However, battlefield digitisation was not considered as a weapon system itself during the Technology Seminar Wargame.

1.3 BACKGROUND

In March 1995 SHAPE announced the need for a study on the implications of new technologies for NATO's land forces operations in the year 2020 to parallel ongoing studies for Maritime and Air Force operations. SHAPE specified that the results be available for use during the Force Goal 2000 Process via the Defence Requirements Review '99 (DDR 99). The DDR 99 process began in December 1997 and ends in April 1999.

In April 1995 a concept paper was circulated to members of AC/243 (Panel 1) for consideration prior to discussion at the next Panel 1 meeting. In September 1995 the agenda for a 30 October 1995 Panel 1 meeting containing a proposal for a Long Term Scientific Study (LTSS) on the implications of new technologies for NATO's Land Forces Operations in the year 2020 (LO2020) was circulated. At the October 1995 meeting members of Panel 1 accepted the proposal for the LO2020 study. SHAPE also agreed to establish a Military Steering Group for the study, chaired by the SHAPE Land Section, with participation from military representatives of the participating nations. COL Joseph A. Roszkowski was designated the MSG Chairman in December 1995. GEN Johnnie E. Wilson, Commander, U.S. Army Materiel Command, signed an LO2020 Charter in February 1996 and designated COL James F. Bald, Jr. as Study Director.

In April 1996 the Defence Research Section LO2020 approved the Terms of Reference for Long-Term Scientific Study 49 on Land Operations 2020 (LO2020) with the United States as lead nation. LO2020 was later designated SAS-006 in the Studies, Analysis and Simulation (SAS) Panel after formation of the Research and Technology Board (RTB) in 1997. In August 1997 COL Albert B. Garcia succeeded COL Bald as Study Director and COL Neil R. Buthorne succeeded COL Roszkowski as Chairman, Military Steering Group.

1.4 INTERNATIONAL SECURITY ENVIRONMENT

The international security environment can be expected to remain in a state of flux well into the 21st Century. Despite the greatly improved security conditions, residual risks to the Alliance will remain from the Cold War Period though not directly attributable to the Cold War. New dangers have emerged and more can

be expected. It is not possible to predict either the time or the place these dangers may erupt into future conflict, but ostensibly the future security environment will be characterised by variety and uncertainty. With the absence of a superpower confrontation in the near term, the current scope and pace of NATO operations, therefore, can be expected to continue along the same lines or increase for the foreseeable future.

NATO Armed Forces will continue to perform their long-standing roles of collective defence, deterrence, compellence, and support to the Alliance. Shaping the international security environment will continue to be a major role for NATO military forces. Diplomatic and economic initiatives will play key roles in this endeavour; however, shaping the environment ultimately will require the limited application of military power to achieve long-term goals of regional and international stability, improved economic climates, and increased democracy.

To accomplish its multiple roles, the NATO land force structure and design must provide the capabilities necessary to operate across a broad spectrum of conflict in peacetime, crisis, and war; to perform effectively throughout the full range of military operations; and perform successfully at the tactical, operational, and strategic levels of war. Clearly, NATO military force structure will require significant revision to meet the current challenges, and more importantly, the challenges that lay ahead on the horizon for the year 2020.

1.5 TECHNOLOGY

Technology is advancing at an ever-increasing pace that presents both opportunities and challenges for military equipment and weapon systems development. Declining defense budgets means that defense research is a relatively minor player on the world scene, especially in the areas of computer technologies, information technologies, communications and biotechnology, which are advancing rapidly. However, there are inherent vulnerabilities within these civil technologies that have to be addressed before they can be fielded as military systems. Defense research must, therefore, identify the key and emerging technologies and draw upon them to focus its limited funding on technologies that will make a significant impact upon the future military capabilities in the year 2020. This study identifies the most critical key and emerging technologies and the impact they will have on military land forces in the year 2020.

2. CHAPTER 2 - CHALLENGES OF THE BATTLESPACE 2020

2.1 AIM AND SCOPE

This Chapter identifies the challenges of the battlespace[1] facing NATO in 2020. It highlights those that are likely to endure and those that will be new. It draws together the implications from the nature of the battlespace described in Annex I, the force description of Annex II together with the Components of Capability discussed in Annex III. It considers the challenges arising from the broad spectrum of political, social, economic, military and scientific factors, although the emphasis in this Long-Term Scientific Study is on the technological drivers and shapers.

2.2 NATURE OF THE BATTLESPACE

2.2.1 Seamless Spectrum of Conflict

In the 2020 battlespace, NATO must be prepared to conduct operations in a seamless spectrum involving conflict prevention, conflict and post-conflict activities. Operations will be multi-faceted, interrelated and often prolonged, in an increasingly joint and combined context. NATO will have expanded and extended its influence. This may strengthen the Alliance, but it may complicate the political dimension, and increase the disparity of national capabilities. There will be no neat classification of operation by type: potential adversaries may range from one extreme of large, all-arms, broadly similarly equipped regular forces (see Annex I: View 1), to the opposite extreme of irregular insurgents and terrorists who may not be identified with nation-states, and whose structure, sophistication, doctrine, training and ethos range from the similar to the radically dissimilar (see Annex I: View 2). There has been extensive use of these two views in this study. In reality, conflict is likely to be a complex amalgam of each view, constantly shifting in emphasis between the two.

2.2.2 Force Components of Capability

Potential adversaries will, to a large degree, have transformed from industrial-age to information-age forces by 2020. Equipment and systems may be drawn from the entire range of capabilities, including legacy systems, state-of-the-art platforms and weapons of mass destruction. There will be much greater exploitation of space, cyberspace[2] and the electromagnetic spectrum. Formations are likely to be smaller, expeditionary[3] and joint. The emphasis will be on deployable, versatile, flexible force, applied at high velocity and precision, at increasingly long-range, with, if necessary, intense and overwhelming violence. A detailed description of these and other characteristics of the component military capabilities required in 2020 is in the "Force Components of Capability (FCC)" at Annex III. FCCs have been used throughout this study as a framework for analysis of the underpinning technologies. A summary of the core components of

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[1] The term *battlespace* encompasses the whole of time, space, perception, and activity. Its use here seeks to convey the many dimensions of conflict which extend beyond the more limited concept of a *battlefield*.
[2] Cyberspace is defined as "The sum of the globe's communication links and computational nodes" (Libiki, Martin: "*The Emerging Primacy of Information*").
[3] The term expeditionary has different meanings and conotations amongst member nations. Here, it is defined as operating a long way from the home base, and, usually, without the benefit of host nation support.

capability from which these characteristics were derived is shown in the following table:

MANOEUVRE	*Movement, Direct-Fire, Mobility, Counter-Mobility, Influence*
FIRE SUPPORT	*Process and Engage Ground Targets*
PROTECTION	*Air Defence, Active and Passive Protective Means, Security, NBC*
CONTROL OF ELECTROMAGNETIC SPECTRUM	*Manage and Assess Own Use, Assess and Deny Enemy Use*
COMMAND AND CONTROL	*Acquire, Communicate, and Assess Information, Plan, Direct, Co-ordinate, Disrupt/Deceive/Destroy Enemy Command and Control, Manage Public Information*
INFORMATION AND INTELLIGENCE	*Collect, Process and Disseminate, Formulate and Direct Effort*
SUSTAINABILITY	*Physical and Psychological Support to the Soldier, Supply and Support Materiel and Infrastructure*
DEPLOYABILITY	*Generate, Train, Mount, Deploy and Insert*

Table 2-1 - Core Force Components of Capability

2.2.3 **Battlespace**

The battlespace in 2020 will be variable in density, non-linear and more dispersed. It will be cellular in nature, multi-directional and increasingly determined by what is above the battlefield in air and space. The 2020 battlespace is thus the whole of time, space and activity. Above all, the term comprehends the fight for perceptions, hearts and minds. It recognises that conflict and the prevention of conflict will continue to be essentially a battle of wills, and that moral superiority and dominance--the decisive imposition of will--is central to success. Herein lie the challenges of the battlespace 2020 that this chapter seeks to address.

2.3 ENDURING FACTORS

2.3.1 **The Soldier**

Conflict is, and will remain, essentially a human activity in which man's virtues of judgement, discipline and courage--the moral component of fighting power--will endure. To out-think, break, and if necessary, kill an opponent, whilst retaining the moral high ground, will be fundamental--if not essential--to success. It is difficult to imagine military operations that will not ultimately be determined through physical control of people, resources and terrain--by people. Thus NATO will continue to demand high standards of leadership, the core values of selflessness, self-reliance, moral and physical courage and integrity, and an

ethos of fighting spirit in its soldiers. A challenge to NATO lies in the erosion of these qualities by the changing nature of contemporary values in its Western Society. Implicit, is the enduring need for well-trained, well-equipped and adequately rewarded soldiers. New technologies will, however, pose significant challenges to the art of soldiering: they will increase the soldier's influence in the battlespace over far greater ranges, and herald radical changes in the conduct, structures, capability and ways of command. Information and communication technologies will increase his tempo[4] and velocity of operation by enhancing support to his decision-making cycle. Systems should be designed to enable the soldier to cope with the considerable stress of continuous, 24-hour, high-tempo operations, facilitated by multi-spectral, all-weather sensors. However, technology will not substitute human intent or the decision of the commander. There will be a need to harness information-age technologies, such that data does not overcome wisdom in the battlespace, and that real leadership--that which makes men fight--will be amplified by new technology. Essential will be the need to adapt the selection, development and training of leaders and soldiers to ensure that they possess new skills and aptitudes to face these challenges.

2.3.2 ***Presence***

The need for decisive and dominant presence, morally and physically, and often over extended periods, will remain a unique and enduring feature of land operations. This will conflict with increasing political and public demand for quick, decisive and clinical actions that cost less in lives and treasure. These influences may not be symmetric between NATO and its potential opponents. The latter may seek to exploit a longer-term strategy, be ingrained with different moral values, and be intent to erode the cohesion and public will of NATO through protracted, bloody operations. This will be a major challenge, underlining a continuing need for land forces with high endurance, robustness and utility across the spectrum of conflict. This is a key driver for protection capabilities and also for non-lethal weapons technologies, both to reduce the cost in lives and to offer more options in both the scale and intensity of military action. Likely to be of increasing importance are technologies that enhance the military capabilities of knowledge and tempo. These qualities will enable NATO to be proactive rather than reactive.

2.3.3 ***Warfighting Ethos***

The most effective means of protection--in every sense of the word from protecting member nations' vital interests to minimising the totality of casualties across the spectrum of conflict--will, ultimately, continue to be the application of overwhelming force if, where, when and how NATO chooses. The massing of simultaneous effects against an opponent's centre of gravity must endure as the bedrock of Alliance security. Fundamental, therefore, is the retention of a core ethos based on combat operations--a requirement to focus on warfighting while being able to adapt for other operations.

[4] Tempo is the rate of activity relative to the enemy. Superior tempo is fundamental to dominate the battlespace. A balance must therefore be struck among the size of a force, its characteristics and capabilities, its combat potential and endurance, and its ability to manoeuvre at a superior rate to an opponent.

2.3.4 Balance of Investment

A perpetual challenge is to ensure best possible value for money out of the processes of procuring combat power. By 2020, defence industries will have continued the process of restructuring on international lines to reflect the general decline in defence spending following the end of the Cold War. This will bring new dimensions to international technology defence research. It is likely to demand greater commitment to international mechanisms such as burden sharing, standardisation and guarantees of role specialisation. To gain real operational advantage at maximum value for money, military scientific research will need to be prudent in its investment. Supported by improved techniques in operational analysis, it must identify and then focus more on those technologies that the civilian market is unlikely to provide. Overall, the balance of investment in technologies will need to be in those that contribute to the broadest range of the components of capability, and in those that provide manifest qualitative step-changes in effect. Policy must deal with the fundamental dilemma of whether to accept near-term risk in favour of longer-term technological dividends. Herein lie the opportunity costs, the greatest pay-off for technological research, and the enduring importance of investment in defence research. With the overall trend within NATO towards smaller, professional armies rather than large conscript forces, maintenance of a technological cutting edge will be crucial.

2.4 TRENDS

2.4.1 The Information Age

A significant change in the conduct of operations is likely to come not from weapons alone, but from the all-pervasive application of information technology. Some suggest that this may herald a step-change in military capability due to the synergistic combination of long-range precision weapons and networks of sensors and data processors (such as digitized real-time sensor to shooter links, combat identification, decision-support and UAV technologies to complement space systems and manned ISTAR). This will demand a new form of fighting, a true system-of-systems approach to combat. It will involve, for example, the co-ordination of multi-national space, sea, air and land-based precision weapon systems, with ranges varying in hundreds of metres to thousands of kilometres, in a highly populated, multi-faceted and multi-agency environment. The effect will be to expand further the continuum of the battlespace, obfuscating the distinction between the strategic, operational and tactical levels of operation. The ability to see will also become conceptually and physically separate from the ability to shoot on a wide range of weapon systems, including direct-fire platforms. This will blur the distinction between direct and indirect fire and, possibly, render heavy and cumbersome combined sensor-shooter platforms less effective in the digitized battlespace. These factors will present NATO forces with major challenges to their doctrine, structures and training, and increase the imperative for standardisation, interoperability and cohesive command and control arrangements amongst the member nations.

2.4.2 *Situational Awareness - Way of Command*

A key variable, and opportunity, will be situational awareness--not just that which gives NATO commanders a better perception of the physical reality of the battlespace, but the greater challenge of providing an understanding of the situation as an opponent sees it. Greater situational awareness will change ways of command. It may, for example, affect the balance between the freedom of action inherent in mission command, and co-ordination and simultaneity[5] provided by centralised command. It will affect the structures and inter-relationships between and within headquarters. How it is managed, will either serve to lubricate future missions or impose friction in the exercise of command.

2.4.3 *Situational Awareness - The Data Deluge*

There is a danger that the volume of raw data generated by future digital systems will swamp commanders with information. The challenge will be to filter data and manage it using enabling technologies, so that it provides commanders with pertinent, easier to use information, rather than raw, unmanageable data. Furthermore the information will need to be differently treated for different levels of command. Military personnel, at all levels, are likely to need new skills and be recruited and trained accordingly. Staff structures will also have to be adapted.

2.4.4 *Situational Awareness - The Media*

Situational awareness will be public and global; an unprecedented, omnipresent and comparably equipped global media network will provide it. This will have a significant influence upon military security and challenge the ability to achieve surprise at strategic, operational and tactical levels of operation. It will be exploitable for moral dominance, susceptible to psychological operations, and a considerable impact upon a commander's freedom of action.

2.4.5 *Information Dominance or Superiority*[6]

The rapid growth of information-age technologies suggests that the need to dominate the acquisition and ownership of timely information will be a key and an all-pervading driver of future operational activity. This will apply not just in conflict, but also in conflict prevention and post-conflict operations. Information operations will increase in importance and be a substantial prerequisite for activities at the tactical, operational and strategic levels, in which the ability to acquire information, to protect one's own information capabilities and to counter an adversary's information operations, will be paramount.

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[5] Simultaneity is the synchronised application of force throughout the battlespace. It may transform the familiar form and structure of military campaigns as a chain of sequentially phased operations. The result will be a total force that simultaneously masses effects or concentrates forces for short duration and leads to dominating the battlespace.

[6] There is a debate amongst NATO nations on the use of the terms *Information Dominance* and *Information Superiortiy*. Here *Dominance* is used as the more powerful term; it implies that superiority can be achieved where and when NATO chooses.

2.4.6 *Utility*

Demands for NATO forces to have maximum utility at minimum cost--to have high utility across the spectrum of conflict--will intensify in the absence of the single determinant and manifest threat of the Cold War, and in the presence of increasing conflicting pressure upon public finances. More flexible structures that are capable of task-organising more readily, increased degrees of peacetime modularity, and multi-rolling of core capabilities at more appropriate levels of readiness, may enhance the utility of military systems. There will be a need to evaluate the advantages and disadvantages of such peacetime measures against the need to foster *esprit de corps* within formations and units. This must recognise that there is a limit to what can be achieved without destroying unit cohesion. The drive for utility underpins the requirement for more versatile systems, and for technologies such as advanced networked simulation techniques for cheaper but more flexible combined training. Exacerbating the challenge of these competing requirements is the blurring of the distinction between Article 5 and Non-Article 5 operations. The traditional view of Article 5 operations is of intense, large-scale warfighting of mobilized troops within the NATO region. For Non-Article 5 operations, the traditional view was of peacekeeping roles, most likely in support of the UN. A future view for Article 5 operations tends towards a combined joint task force, operating on the outskirts of NATO's area of responsibility, with very high combat capability but at scales of effort considerably short of national mobilisation. A future view of Non-Article 5 operations includes peace enforcement and involves scales of effort and capabilities significantly greater as those required for participation in peace-keeping missions. Hence the blurring, from a military perspective, of the distinction between Article 5 and Non-Article 5 operations, underlines the consequent need for forces that have utility in both, and emphasis on greater strategic manoeuvre of projectable forces.

2.4.7 *New Vulnerabilities*

Continuing investment in technologies should ensure that NATO maintains what many believe to be its currently almost unassailable advantage in conventional (View 1) warfighting. However, history shows examples of how low technology opponents have dealt successfully with more advanced technologies wielded by well-trained troops from highly developed nations. High technology encourages the paradigm: "what works today, will not work tomorrow precisely because it works today". The challenge for NATO is to anticipate the effectiveness of new high technology countermeasures. Experience of history also suggests the need to maintain a reversionary or back-up mode when critical systems do fail. This is likely to become more difficult to achieve as new computerized techniques mask basic operating procedures. There must also be careful and constant appraisal of how NATO's potential adversaries might employ asymmetric responses. A particular concern will be the need to counter the threat from proliferation and ease of delivery of low technology weapons of mass destruction. Continued investment in protection against guerrilla and terrorist threats is inevitable. Further vulnerabilities lie in the disparity of the technical capabilities of the Alliance partners. If more of the member nations can successfully tap new technological developments the result will be more effective coalition operations.

Where this is not achieved, there may be significant asymmetries in capability and the consequent political will to act. This may, in turn, introduce new vulnerabilities and militate against tempo and simultaneity of action within Alliance formations. Such asymmetries may be inevitable, and may already be appearing, for example in space. NATO must prepare new concepts and doctrine to mitigate these effects, for example by the use of intra-formation boundaries for co-ordination and control--the latter based less upon traditional geographical lines on the map, but more in space and the electromagnetic spectrum.

2.4.8 *Analysis and Doctrine*

Intelligence and information assessment must focus as much on "ends and ways" as it does on "means"[7]. This will be a far more difficult task now and for the foreseeable future than it was during the well-defined threat in the Cold War. The analysis techniques used must recognise the human interactions, multi-agency, deterrence and national-cultural dimensions to conflict, and be capable of representing not only the attrition effects of weapon upon weapon, but also the effects of weapon upon will and the effects of will upon will. Fundamental, too, is the importance of a dynamic, coherent NATO doctrine to give direction to research by identifying the military priorities and taking account of emerging technologies.

2.4.9 *Urbanisation*

Urbanisation is likely to pose a significant challenge to NATO land forces. By 2020 some 70% of the world's population will live within urban areas. The greater transparency of non-urban operations--enabled by real-time ISTAR technologies--and the likelihood of continued conventional force dominance by NATO forces, will place any counter-balance of advantage to NATO's adversaries away from 20th Century-style open-terrain engagements and into the urban -sprawls. It will be in the cities, more than anywhere else, where would-be adversaries will have ready access to global information-age sophistication, and where they are better placed to threaten vital information infrastructures. Legacy systems that are ill-designed for urban combat, and the need to operate with less manpower, may exacerbate this challenge. Operating in urban terrain requires high agility: the essence will be to manoeuvre and support with very high degrees of protection and tempo. The use of autonomous weapons to distance soldiers from threats such as mines and booby traps, may be effective and reduce NATO casualties. However, their use may be limited by civil pressures and international legislation--such as that imposed on the use of land-mines. Urban operations will place particular challenges on technology to achieve safe areas of operation and co-ordinated effect with versatile munitions, ranging from high explosive blast effects to electromagnetic means. The urban environment will be a key driver for non-lethal weapons and barrier technologies to reduce the risk of fratricide.

[7] Ends, Ways and Means. The balance between ends, ways and means will become increasingly complex for commanders and their staffs; consideration of an enduring post-conflict settlement will become a fundamental part of campaign planning. Commanders will have to consider political, moral, legal, socio-economic, environmental, cultural and international elements in developing joint and combined campaign plans in addition to more traditional military factors.

Furthermore, the urban environment will be the most challenging environment for ISTAR and for dominance of the electromagnetic spectrum.

2.4.10 **Sustainment**

Technological developments will increase the tempo, range and speed of operations placing greater demands on sustainability and reliability. This changed environment, with greater autonomy of operational structures, is likely to break down the distinctions between combat, combat support and combat service support arms. Enhanced logistic and medical reach, plus self-sufficiency to provide strategic and operational mobility will also be required. This puts a premium on efficient, interoperable, reliable and timely logistics to achieve the required balance among size of force, its combat potential, endurance and sustainability. This poses a significant challenge on existing, largely nationally organised logistic arrangements. It also calls for complementary logistic technologies such as improved reliability, prognostic or diagnostic software and asset tracking. Overall, it implies a need for a transformation in logistic affairs.

2.5 CONCLUSIONS

NATO military superiority is likely to continue to deter potential opponents from head-on symmetric conflict in 2020, provided a core ethos based on warfighting operations is retained.

- A key driver is strategic and operational tempo in the less dense battlespace. This largely determines the requirement for smaller, leaner, more versatile forces, in which advances in logistics, C2, ISTAR and long-range precision engagement will be highly significant.
- Asymmetric threats, in terms of ways and means are more likely. This underpins a requirement for improved force-protection against a spectrum of attacks, including weapons of mass destruction and terrorism.
- Overwhelming force will remain the principal means of protection, both as a means of deterrence and in conflict.
- Technological development will blur the distinction between direct and indirect fires and break down the distinctions between combat, combat support and combat service support.
- A broad range of increasingly agile and versatile forces must be maintained for utility throughout the spectrum of conflict. This is a key driver for multi-role and multi-purpose systems. Over reliance upon single systems will impose vulnerabilities.
- Doctrine and concepts must be dynamic and iterative recognising that many weapons will be used in a way and for a purpose not originally envisaged. They also have to mitigate effects resulting from disparities in the technical capabilities of NATO members.
- The most demanding, yet probable environment for conflict will be urban.

- Incremental improvements to platforms will have less overall effect in the intervening period than those technologies that add a systemic, qualitative step-change to a broadest possible range of components of capability. There is a strong imperative to deliver these technologies into service more efficiently.
- The exploitation of space, information dominance, digitization and the electromagnetic spectrum will be the new high ground enabling major advances in precision, speed of manoeuvre and massing of effect at far greater ranges. Together, these capabilities are likely to herald significantly different new ways of conducting operations throughout the spectrum of conflict. Layered and robust ISTAR, robust to counter measures, available 24 hours, all weathers, and linked to highly responsive long-range precision attack systems will be vital. So, too, will be information operations in the public domain and with the media.
- Human and organisational behaviour will continue to be a major, if not dominant, factor. New technologies, particularly information technologies, will challenge the art of soldiering, but, properly harnessed, will serve to assist it.
- Standardisation and interoperability, in ways as well as means, will be of greater importance in achieving tempo and simultaneity in joint and combined operations. This will maximise the exploitation of the benefits, for example, of digitization, and mitigate friction imposed by an increase in the likely number of nations participating in operations.
- Logistic drag is the antithesis of manoeuvre warfare. There is an imperative to identify and exploit the technologies that will reduce it.
- The balance between strategic and tactical mobility will be significantly affected by the availability of host nation support in campaign operations.
- The need for change in force structure is inescapable and flows from the changing security environment, the increased likelihood of multi-national and multi-agency operations, the impact of emerging technology, the evolving nature of conflict and the continuing pressure on resources. Organisations at lower levels may need to be able to perform joint and combined functions previously conducted at higher levels.
- There will remain differences in the pace and degree of modernisation between the member states, emphasising the need for standardisation between legacy and new systems.

2.6 RECOMMENDATIONS

It is recommended that:

- Investment is focused upon more versatile forces, with particular emphasis in information dominance, logistics, C2, and ISTAR linked with longer-range precision weapons.

- Investment is increased in force-protection especially against weapons of mass destruction.
- NATO maintains a broad range of agile and versatile forces.
- Space based capabilities be considered as an area of growing importance.
- Technology must be integrated with doctrine, concepts, structures and training, to maximise its impact.
- Greater emphasis is placed on the capabilities required for operations in urban areas.
- Priority is given to investment in technologies that provide a step-change to a broad range of capabilities, rather than incremental improvements to single platforms.
- More effective initiatives are pursued to improve standardisation and interoperability amongst member nations as essential pre-requisites for the introduction of new members, systems, and procedures.

3. CHAPTER 3 – IMPACT OF TECHNOLOGY ON LAND OPERATIONS IN 2020

3.1 AIM AND SCOPE

The aim of this chapter is to identify technology trends and to assess the impact of technology for Land Forces in the future battlespace; its scope is restricted to those technologies that can reasonably be expected to be developed and fielded by 2020.

3.2 TECHNOLOGY TRENDS

It would be easy if the military challenges posed in Chapter 2 could be unambiguously converted into new military systems and the contributing technologies required to deliver them written down from a long check list. In the real world technologies do not develop by themselves. Instead a complex mixture of military, political, economic, social, environmental and technical drivers decides when technologies are available.

In asserting which technologies are likely to be of crucial importance we must also take due note of some spectacular errors that have been made in the past, e.g.

> *"There is no likelihood that man can ever tap the power of the atom", Robert Millikan, Nobel Laureate, 1923*
>
> *"Heavier than air flying machines are impossible", Lord Kelvin, President of the Royal Society, 1885*

Within twenty years or so both of these predictions were dramatically disproved. Coincidentally, this is also the timescale of the LO2020.

Military systems usually take so long to procure that fielded technology in 2020 must already exist in 1998, albeit in the form of basic and applied research. Thus the prediction task for LO2020 is to take today's "blue skies" research and deduce, in general terms, the potential defence applications that it will satisfy. In addition to such newly emerging technologies, for example: biotechnology, it is also evident that the military systems of 2020 will be significantly affected by the "boom" technologies of the late 20th century:

- digital electronics, microprocessors and computing in general;
- automation and robotics;
- high bandwidth (digital) RF systems including communications and radar applications
- novel materials;
- nuclear power.

While the use of nuclear power in the battlespace remains a difficult policy issue for the members of NATO, nuclear devices and other weapons of mass destruction will be a significant threat, including terrorist situations. Nuclear systems illustrate another important point, which is that technologies in

themselves will not provide answers to the military challenges posed in Chapter 2. They can only do so as part of larger military systems which in some cases will be legacies from the present day. For example, the full deterrent potential of nuclear weapons was only achieved when nuclear technology was combined with missile technology, which in turn depended on propulsion and navigation/guidance sub-systems. Next, missiles required launch platforms, such as submarines, and the whole had to be linked with surveillance and targeting systems via an efficient command and control mechanism. Therefore, it is the complete system which delivers the effectiveness, not any particular technology in isolation.

Another example of the contribution of individual technologies to overall system effectiveness can be derived from the role that electronic devices play in Command and Control systems. On their own, VLSI (Very Large Scale Integrated) chips, Analogue/Digital converters and high speed microwave devices may not appear important, yet they are at the heart of information processing and communication systems without which modern Command and Control would not be possible.

3.3 METHODS USED TO IDENTIFY KEY TECHNOLOGIES

A number of separate, independent approaches were used to identify the Key Technologies for 2020 capitalising on individual nations expertise in particular methodologies. These approaches involved different sets of experts and occurred at different times.

3.3.1 ***Critical Technology List***

In the first approach, the knowledge and experience of the LO2020 Technology Group members was captured in an exercise which generated a "top down" Critical Technology list containing eleven broad technical areas (Table 3-1).

Once the list had been agreed, individual nations undertook to provide detailed information in two or three separate areas, where necessary, subdividing the technologies into their main constituents. The resulting papers on underpinning technology are contained in Annex IV.

3.3.2 ***CRITECH Exercise***

In complete contrast to the brainstorming exercises, the "CRITECH" exercise, started by examining in great detail, albeit judgementally, the feasibility, effectiveness and cost of a large number (142) of very specific technologies covering the entire spectrum of military relevance as well as a significant number that were predominately civilian. A computer-aided group decision system was used for this task, on which 24 national experts worked. The outcome was a completely auditable shortlist of 63 technologies deemed to be the most relevant from the joint perspectives of feasibility and effectiveness. Cost did not feature explicitly in this choice, except that it was used to resolve average situations. Further analysis led to a shorter list of 34 technologies, of which 67% were dual,

and only 33% specifically military. A full report of the exercise is contained at Annex V.

Table 3-1 identifies the high level Critical Technologies and the low level underpinning technologies identified in CRITECH and in the MNE brainstorm.

Table 3-1

1. Electrical Technologies

Electrical Batteries
Electrical Power Cells
Conversion of Solar Energy to Electricity
High Energy Physics Techniques (including plasmas)
Transmissions/Powertrains

2. Sensor, Directed Energy and Communications Related Technologies

Lasers (all types)
Power Sources (RF, micro and mm wave)
DEW Lasers
RF Sensors/Antennas - Active Radar
Very High Power Electronic Components
Electromagnetic Compatibility Simulation and Protection
Integrated Systems Design (incl. EMC)

3. Computing Technologies

Software Engineering
Protocols (incl. LANs & WANS)
Architectures
High Integrity Computing (incl. Safety Critical Software)
Secure Computing Techniques (Incl. MLS)
CIS Design
Software Programs for Complete Material, Modelling and their Implementation Processes
Database Design
Digital Signal Processing Techniques
Optical Signal Processing Techniques
Image/Pattern Processing Techniques
IKBS/AI/Expert Techniques
Data Fusion Techniques
Simulators, Trainers & Synthetic Environments

4. Communications Specific Technologies

Communications Design - RF
Encryption
High-Sensitivity Reception Technologies
Wide Bandwidth Networks

5. Electronic/Information Warfare Technologies

RF Sensors/Antennas - Active Radar
Very High Power Electronic Components IW Defence Techniques

6. Electronic Devices

IR Sensors (EO Systems)
Explosive Detection Systems
Explosives Detection Techniques (incl. bulk & trace)
Chemical & Biological Detection (CB Agents & Toxic Chemicals)
Rapid Microbiological Detection Methods

7. Biotechnology

Medical Materials Including Blood Products & Biomimetics
CB Countermeasures - Medical
Vaccines from Genetic Engineering

8. Structural Materials Technologies

Non-Destructive Evaluation & Life Prediction
IR Absorbing Materials
Radar Absorbing Materials
Smart/Functional Materials (Sensors/Actuators/Biomimetics)
Platform Protection Measures - Armour.
Aerodynamic Designs
Structural Designs
Stealth Designs
Manufacturing Processes/Design Tools/Techniques
Reduction of Automotive Vehicle Mass
Materials for High-Temperature Processes
Optimised-Performance Concrete
Tools for Understanding the Structural Integrity of Buildings
Materials and Concepts for Reduction of Mass
Novel Energetic Materials
Physical Protection Measures (Eye, Body Armour.)
CB Protection - Physical (IPE, COLPRO)

9. Human Factors and Man-Machine Interface

Knowledge Management
Cognitive Performance
Decision Making
Human Behaviour
Human Performance
Social and Cultural Issues
Psychological Issues
Human Computer Interfaces/Man Machine Interfaces

10. Precision Attack Technologies

Low-Cost Inertial Components, Low-Cost GPS with Protection Against Jamming
Warheads (all types) including Insensitive Munitions
Navigation Systems
Weapon Guidance & Control (for Sea, Land, Air)
Dynamic Management Control of Traffic Flow
Brilliant Munitions

11. Automation and Robotics

Automation & Robotics
Intelligence Automated Systems
Unmanned Aerial Vehicles Control

12. Examples of systems which use 2/3 technologies from the Critical Technology List

Health Monitoring Systems (incl. HUMS)
IFF/NCTR/NIS
UAVs, Unattended Weapons

Table 3-1 - Land Operations 2020 Shortlist Technologies

3.3.3 ***Technology Seminar Wargame***

The Technology Seminar Wargame (TSW) was the second major exercise of the LO2020 study. The goal was to assess the effectiveness of a number of concept weapons and platforms which embodied the Critical Technologies by means of a structured debate between military and technical experts. In the Wargame, two "Blue" teams and one "Red" team examined a set of twelve concept systems in three scenarios, including one specifically related to "View 2" operations.

In choosing the twelve TSW concepts, the most important aim was to address as many of the detailed Force Capability Characteristics provided by the Military Steering Group (Annex III) as possible, while at the same time reflecting the full range of possibilities suggested by the participating nations. However there are limits to the sorts of concepts that can be included: technology seminar wargames are primarily designed to explore weapons and platforms and they are

not effective when it comes to modelling C3I systems. Hence "Digitisation", though undoubtedly very important, was not one of the chosen concepts. The chosen concepts are listed in Table 3-2, (full details of them are included in Annex VI).

The impact of individual technologies on the future battlefield is difficult to assess because so much depends on exactly how the technologies are used in systems and what the circumstances of future operations are. An enabling technology used to improve the overall effectiveness of a number of systems by a small amount may actually be more valuable in the long term than a single "war-winning" technology that could only be used in a restricted set of circumstances.

3.3.4 ***MNE Brainstorm***

During the Multi-National Exercise, the Critical Technology list was independently validated, with the addition of a small number of underpinning technologies.

TSW1	High Mobility Vehicle
TSW2	Concrete Foam
TSW3	Non-lethal barrier
TSW4	Electric Direct Fire Heavy Weapons Platform
TSW5	Modular UAV
TSW6	RF Directed Energy Weapon
TSW7	EO Sensor Dazzler
TSW8	Unattended Robot Ground Weapon
TSW9	Advanced Artillery System
TSW10	Micro-electrical-mechanical systems sensor field
TSW11	Indoors/Outdoors UAV
TSW12	Robot Sentry

Table 3-2 - Concept systems explored in the TSW

3.4 RESULTS OF THE CRITICAL TECHNOLOGIES

A number of preliminary conclusions were drawn relating the impact of technology on future military operations. Based on the insights gained in the TSW, the characteristics of all the other concept candidates, the material contained in Annex IV, and discussions during the MNE,. Naturally, this is largely a judgmental process; however the point of the LO2020 study and its various constituent exercises is that these judgements are based on the best collective information available in the participating nations. In presenting these assessments it was decided to use the framework provided by the Components of Capability (Annex III), recognising, that many of the Components are simultaneously addressed in a single piece of equipment.

The following sections separately address each of the eight main components of capability at the sub-component level, where it is appropriate to do so, and conclude by summarising key issues.

3.4.1 *Impact of Technology on Manoeuvre (Conduct Manoeuvre, Conduct Direct Fire, Provide Mobility, Provide Countermobility, Control Area of Influence)*

Conduct Manoeuvre

During the next 20 years, there will be evolutionary changes in all aspects of land and air platforms leading to improved speed, range, and fuel consumption as well as in reduced signatures. The change will be led by improvements in materials and the way materials are used in subsystems - for example the aeroelastic tailoring of rotorcraft blades and the adoption of active suspension systems for land vehicles. Lightweight vehicles, sensors and weapons will enhance air transportability, and crew reduction. Increased automation will further reduce size and weight.

Ultimately, the terrain will limit the speed of land vehicles. To achieve the greatest speeds, it will be necessary to use air manoeuvre platforms such as helicopters and tilt rotor vehicles.

A potential revolutionary change can be expected from the introduction of Electric and Hybrid Electric drive technologies. Materials advances, in the form of new insulators, magnetic materials and semiconductor switches, coupled with microprocessor based control systems are the key enabling technologies. The main advantage of electric drives is complex mechanical transmission systems in all current vehicles could be replaced by wires conducting electricity to hub mounted electric motors, thereby removing the need for bulky transmission systems. The result will be significantly smaller vehicles that are more manoeuvrable as a result of individual wheel control, with greater reliability resulting from the availability of more than one motor whilst preserving the speed of conventionally driven platforms. Fuel savings of as much as 50% are another advantage of hybrid systems which arises simply because the diesel or gas turbine generator can run at peak efficiency. This, combined with increased efficiencies elsewhere in the system, it is expected there will be an order of magnitude increase in power generation capability which will become the major basis for a revolution is this area. When running on battery power, such vehicles will also be stealthy, emitting no engine noise or hot exhaust gases. These advantages will apply equally to View 1 and View 2 operations. In expeditionary operations a further advantage of extremely long-ranges (1000s of km) could be realised by the use of novel Fuel Cell technology based on "Metallic Hydrogen" as a primary fuel source. The fuel efficiencies of hybrid or direct electrical propulsion will make a major contribution to reducing the logistic burden. In the TSW, a modular vehicle concept which embodied hybrid electric drives was considered to be the most useful of all concepts studied in all three scenarios.

Conduct Direct Fire

Ongoing research into conventional (tank) gun technology could be expected to produce 10-30% improvements in effectiveness by 2020, primarily by moving to 140mm calibre. However, 140mm ammunition will require autoloaders and the corresponding weight and size penalties for a complete vehicle may be unattractive.

Recently molecular dynamics modelling techniques have shown that novel explosives that have five times the energy density of TNT may be realisable. This development could re-invigorate conventional gunnery.

On the other hand, the electromagnetic gun will, if perfected, have a revolutionary impact on direct fire engagements. It will be capable of launching hypervelocity projectiles at speeds well in excess of 2 km/s that will in turn be capable of defeating the frontal armour of virtually any target. After a number of years' research already in several NATO countries, it is clear that the challenges posed by this system are severe and the costs high. It may, therefore, be too optimistic to expect that electromagnetic guns will be available in 2020. A concept "Electric Heavy Direct Fire System" was studied which had an electromagnetic gun as well as using sophisticated electric armour and hybrid electric drive. This was deliberately intended to reflect an extreme view of what the next generation of tanks could be like. This system scored highly in terms of military attractiveness, especially as a psychological weapon in View 2, but against a high technology opponent many players questioned its utility, not least because it would seldom be able to see and engage its primary threat which by 2020 will be long-range precision attack systems driven by sophisticated ISTAR, and very short-range weapons in certain situations.

High power lasers could provide another radical alternative to conventional direct fire capability for the future. Some (non-NATO) nations have fielded such systems already. For NATO nations, the main use of laser weapons will be to defeat EO sensors on manned and unmanned platforms because the UN Protocol on laser-blinding weapons limits their use against personnel.

Radio Frequency Directed Energy Weapons (RF DEW) could provide another revolutionary direct fire asset in 2020. Modulated RF signals have the ability to disrupt electronically controlled systems ranging from command and control computer systems to the engine management systems of modern vehicles. RF directed energy would be a valuable non-lethal weapon because it can readily provide soft kill of enemy electronic systems without harming personnel. The main difficulty is the power supply and storage: to have a range of 1-5 km in a stand-alone system for point air defence will require a large power generator, even by 2020. However the power/range problem could be overcome for a different class of targets by using explosively generated RF signals from devices fitted as warheads, which, even without course correction technologies, could be expected to get within 100-200m before exploding. Both of these RF concepts were included in the TSW and were found to be particularly valuable in the View 2 scenario.

Provide Mobility

The detection and clearance of landmines will continue to be one of the most important challenges facing NATO nations, including peace support activities. By 2020 we can confidently expect that a number of detection techniques will have matured, for example ultra-wide band radar, Micro Electrical Mechanical Systems (MEMS), laser induced fluorescence, bio-luminescence and multispectral sensors and that mines and certainly minefields will be detectable from low flying UAVs.

Some techniques for destroying mines are already relatively mature, however highpower microwaves could provide an attractive alternative by 2020.

Well before 2020 it will be possible to operate battlefield engineer equipments remotely using teleoperation (and possibly virtual reality) so that individual operators are not exposed to hazardous environments.

A particular idea, which captured many imaginations during the LO2020 study, was the concept of "Concrete Foam" as a flexible mobility aid. This could be dispensed from a variety of sources and would rapidly harden, providing temporary repairs to roads, runways and buildings as well as bridging anti-tank trenches.

Provide Countermobility

A number of candidate technologies are being studied throughout NATO to provide acceptable alternatives to anti-personnel landmines which have been banned by the Ottawa Convention. It seems likely that combined sensor and (smart) mines will be required to provide area denial with appropriate political accountability. Non-lethal barriers were also considered. For example, an anti-traction agent in which a polymer powder was "activated" by wetting, producing a surface as slippery as ice.

Control Area of Influence

Of main importance will be the capability to guard relevant but otherwise empty areas and to react to enemy moves in them. Sensor technologies, MEMS, autonomous systems (robotics) and biotechnology development will enhance capabilities in this field. For a speedy reaction to enemy moves in unguarded areas, long-range systems and the capability to quickly erect barriers are required. The technologies involved in these areas are discussed under Fire Support, Protection, and Command and Control.

Key Issues Manoeuvre

- Hybrid electrical power generation and drive technology will enhance capability while reducing weight and size
- Enhanced direct-fire capabilities will include radio frequency DEW, electrical energy weapons and improved warhead functionality
- Present efforts in demining and de-pollution will deliver detection (based on sensor fusion including biotechnology and MEMS) and clearance capability (based on robotics amongst others) to provide the necessary means pertaining to the area of mobility. As to counter-mobility further developments on (non-lethal) alternatives for AP-mines are necessary.

3.4.2 *Impact of Technology on Fire Support (Process ground targets, Engage ground targets)*

Process Ground Targets

By 2020 the Digitisation of the Battlespace will provide an IT infrastructure in which targets identified by a variety of sensing systems can be tracked and displayed to all major fire support assets in theatre. Potential systems include effective Battle Damage Assessment (BDA) and Computer-based decision aids. The decision aids will be based on naturalistic reasoning techniques, moderated by the rules of engagement and will present prioritised target list suggestions to commanders.

Engage Ground Targets

The technology of 2020 will enable ground commanders to simultaneously strike and defeat a range of high value, highly protected enemy assets, such as command and control, air defence, mobile missile launchers and main battle tanks at ranges of hundreds of km, with minimum collateral damage. Indeed longer ranges will also be possible, at greatly increased cost, using laser guided bombs dropped from fixed wing aircraft and cruise missiles, both of which are already available and both of which are capable of delivering accuracies down to 10m. The novel explosives, capable of providing more than five times the present mass-effectiveness mentioned in "conduct direct fire" may revolutionise this field. Alternative techniques for engaging targets, such as MEMS weapons (especially against electronic systems) and non-lethal weapons will also be available.

Advances will be made both in the delivery system and the warheads. For ranges up to 50 km or so, conventional artillery will provide the fastest delivery system. The additional control possible in hybrid Electro-Thermal Chemical propulsion systems and GPS, course- corrected shells will reduce the effect of muzzle velocity errors on strike point by an order of magnitude compared to unguided systems. Missiles will be required for longer ranges or for larger payloads than a 155mm shell can carry. These will be guided by inertial or GPS based systems but are likely to trail a fibre optic umbilical, down which seeker information will be passed, enabling precise specification of final aim point by a human operator. This could be an important source of information for Battle Damage Assessment (BDA).

Warhead designs present a spectrum of increasing complexity. Unguided bomblets are already in service; they use the scatter gun principle to increase the chance of a hit and self-evidently their effectiveness is a trade-off between size and number. Sensor-fused munitions represent a step increase in complexity and effectiveness. Descending by parachute from artillery shell or missile, they only fire when an onboard sensor detects a target, typically at ranges of up to 100m. Finally, terminally-guided sub-munitions (TGSMs) rely on mm/IR seeker technology and aerodynamic guidance to deliver a precise strike. Because of their complexity and size, TGSMs are more likely to be borne by missile systems rather than artillery. Defensive Aids Systems (DAS) will be fitted to high-value

land platforms to counter such systems, requiring in turn, counter-countermeasures to be fitted to missiles.

Intelligent fusing provides a different form of precise attack when the geometry of particular installations is known. As a warhead penetrates the various hard and soft protective layers surrounding the target, sensors within the fuse detect the changes in resistance and only detonate the device when it is in the correct location.

To achieve ranges in excess of 100km, or to attack from unexpected directions without resorting to the expense of cruise missiles, it would be possible by 2020 to have a "Robot Ground Weapon" in which an unattended pod of missiles could be emplaced in critical locations prior to use when triggered by appropriate sensors, on say, a long-range UAV.

Key Issues Fire Support

- Sensor to shooter integration will allow to make best use of the capabilities of fire support systems.
- Munitions integration will enhance range (ETC-weapons), precision (sensors and guidance), effect (improves warheads and high energetic materials) and assist in BDA (Multi Domain Smart Sensors).

3.4.3 Impact of Technology on Protection (Provide air defence, Provide protection for forces and means, Provide security, Provide NBC protection)

Provide Air Defence

The Air threat will grow in quantity and quality, including both Guided and Long-Range Ballistic Missiles. This development puts a premium on early warning, identification and prioritising engagements of aerial vehicles. Radar, optics, lasers and acoustical technologies will have to be further developed and integrated into the battlespace IT infrastructure.

Air defence is one of the most challenging aspects of precision attack and for the time being it is likely to be dominated by missile borne systems. Improve seeker technology, in particular multi-spectral and phased array mm-wave seekers, will improve weapon accuracy, reduce missile size and hence increase agility. Improvements in processing and guidance algorithms will aid in discriminating against countermeasures. For shorter ranges, the technology of Radar Information Fields (RIF) will provide an alternative to Command to Line of Sight (CLOS) guidance that could provide a second line of defence in the form of small, very fast, very agile missiles designed actually to hit incoming enemy missiles or aircraft. Finally, at the closest ranges, ECM, in the form of high power RF and Laser technologies offer the possibility of "instantaneous" soft kill of any electronically or electro-optically controlled munitions. Such systems are actively being researched now and could easily be fielded in 2020. Of these two, the RF DEW is likely to be preferred because of its all weather, non-lethal capability. In contrast any Laser based system will be affected by the weather. Moreover, its

use will undoubtedly be severely restrained by Rules of Engagement designed to avoid blinding.

Provide protection for forces and means

Making equipment harder to detect is a key element of protection. In part, stealth can be achieved by design, but reduced signature coating or construction materials will also be essential. By 2020 it is possible that tunable, multi-spectral coatings will be available which will allow the signature of key assets to be changed according to their particular environment, achieving a chameleon effect. Reducing unwanted electromagnetic emissions will also be required. By combining various design and materials technologies it will be possible to tailor the signatures of all equipments so that high and low value platforms look alike.

Increased use of interconnected computers, communications and other electronic systems will offer many new potential vulnerabilities. A robust integrated defensive capability which will detect, identify, deter and react to hardware and software threats will be required. There will be rapid developments in COTS software and hardware in areas such as encryption, authentication, virus detection, network monitoring and artificial intelligence. These developments must be continually monitored and rapidly applied to military systems.

Increased mobility can also provide protection but conversely, it can also increase the threat. This is particularly so for View 1 operations where an enemy could be expected to have sophisticated ISTAR assets specifically designed to identify moving targets.

Decoys are a well-established protective system. By 2020 these will have the capability to obscure thermal and visual wavebands and be an integral part of defensive aids suites (DAS). Developed from the DAS systems with which most fast jet aircraft are fitted, DAS in the battlefield will rely on active or passive sensors to detect enemy missiles, enemy sensors like radar warning receivers (RWR) or TGSMs and automatically trigger countermeasures. These countermeasures may range from IR flares and jammers to RF weapons. DAS systems are likely to be very expensive, even by 2020, and so will only be fitted on the most important ground and army aviation assets. Longer-range decoys could also be fielded, using autonomous or semi-autonomous robotic platforms capable of mimicking the electro-magnetic signature of, say, a mobile headquarters vehicle, or an attack helicopter.

For individual soldiers, development of material systems and a better understanding of penetration mechanics will contribute considerably to personnel protection (i.e. body armour). Thermal suits will help reduce IR signatures and provide protection in extreme climates.

Armour research will also produce significant benefits by 2020. Advances in thick section composite materials will deliver lightweight and hence fast vehicles with a reasonable level of ballistic protection but without metal hulls, ideal for both View 1 and View 2 operations. Ceramic materials (e.g. Alumina, Boron Carbide) can achieve spectacular performance in defeating both chemical energy and kinetic energy weapons, with the particular advantage that their effectiveness increases in proportion to the speed of an incoming projectile. New designs to inhibit

cracking will soon provide ceramic and armour with unprecedented impact resistance. By 2020 cheaper manufacturing techniques will make ceramic and Titanium based materials more affordable for battlefield use. Titanium is superior to steel in virtually every material property and could deliver the same ballistic protection at only 40% of the weight. Vehicles incorporating Ceramic or Titanium armours will therefore be lighter, faster and better suited to air transportation. Finally, "Electric Armour" will provide another lightweight system of exceptional effectiveness against chemical energy attacks. Here, the principal is that very large amounts of electrical energy are discharged through the incoming projectile, thereby disrupting it and rendering it ineffectual. Keyed by appropriate sensors, electric armour will provide a flexible "smart" alternative to explosive reactive armours.

Avoiding fratricide is a particularly important aspect of protection. So far as this is concerned, current research indicates that question-and-answer mm-wave beacons fitted to all allied assets are most likely to the fielded system in 2020. The introduction of corner-cube arrays will enhance covertness and reduce costs of IFF systems. Situation awareness, facilitated by digitisation of the battlefield, will be relied upon to avoid long-range, indirect "friendly" attacks.

In short, future weapon and platform designers will have a wide range of protective technologies available from which they can construct the most appropriate system for their particular applications, be it frontal armour for a heavy tank or all round protection for vehicles designed to fight in urban environments.

Provide Security

The provision of security is to do with detecting and preventing an enemy from getting into a position to attack. As such it can be achieved by a number of means, including pre-emptive attack. A useful contribution that the LO2020 technologies can provide is, however, in the field of remote sensing. This will be discussed fully in the section on Information and Intelligence, but mention should be made of the use of unattended, interconnected ground sensors. For example, using Micro-Electrical Mechanical Systems (MEMS) technology. Individual sensors (acoustic, thermal, chemical) within this field would have limited sensitivity but they would be small (cm size) and therefore hard to detect. However, the field as a whole would be a very powerful system, capable of detecting enemy intrusion and communicating this covertly, incorporating advances in wireless networking and internet technology. Such a field could be hand scattered or dropped from a UAV, and the concept would be equally useful in "View 1" and "View 2" operations. This concept was played in the TSW and it was considered to be as valuable as the various artillery and direct fire weapons systems.

Provide NBC Protection

Advances in nanotechnology, MEMS, biotechnology and information processing technologies will yield progressively smaller NBC detectors, so that by 2020 it should be possible to have miniature replacements for the current truck-sized systems. These miniature systems could be deployed in a variety of systems with different ranges. Indeed research is currently going on to produce MEMS

detectors of biological agents. Biological detectors interspersed in a MEMS security field could provide a dispersed detection system capable of providing early warning of BW attack.

Key Issues Protection

- A combination of different technologies will be necessary to provide protection against Guided and Ballistic Missiles.
- Active protection will improve survivability and allow more agile platforms (new materials, laser-, sensor-, RF- , Electric armor and other technologies).
- Robust Combat Identification Systems (sensors, MEMS) are indispensable to avoid fratricide.
- Enhanced body armour will provide the necessary protection to personnel (new materials).
- NBC defence, especially against (low technology) biological and chemical threats, will enhance the survivability and hence the effectiveness of armed forces; biotechnology will provide these capabilities.

3.4.4 ***Impact of Technology on Control of the Electromagnetic Spectrum (Manage own use of the spectrum, Assess degree of control required, Deny enemy use of the spectrum)***

Manage Own Use of Spectrum

Managing own use of the spectrum means ensuring that systems which transmit and receive in the EM spectrum are deconflicted. There are a wide variety of systems which need to be managed, ranging from communications systems supporting battlespace digitisation, through active surveillance systems such as RADAR and LIDAR, to passive surveillance systems such as ESM and millimetric imaging. The possible use of high-power microwaves and RF weapons, as well as conventional EW, will pose special problems, in particular bandwidth availability.

The EM Spectrum does not respect national boundaries but is formed by a mix of national and civilian emissions which are constantly changing. Management of the spectrum will require an analysis system which links databases containing information on equipment characteristics, deployments, geographic data and international regulatory data. This system should be connected to ESM systems which are capable of providing a dynamic representation of the EM spectrum, and various reporting and deconfliction tools.

The use of common standards and protocols (e.g. STANAGS) will help management of the EM spectrum. However, the increasing complexity of emissions, use of war reserve modes, and national sensitivities over releasing data on their systems will continue to pose challenges.

Control of the EM spectrum within urban terrain will pose special problems, but will be assisted by developments in the detailed 3D mapping of urban areas, and in RF propagation analysis.

Assess Degree of Control Required/Deny Enemy Use of the Spectrum

It will not be possible to deny the enemy use of the spectrum in general. It may, however, be possible at specific points in time, space and frequency of our choosing.

Denying the enemy use of the electromagnetic spectrum amounts to jamming. The essentials of this process are unlikely to change much by 2020, however technology will offer new platforms on which jammers can be deployed, such as high flying UAVs. Advances in RF power generation, digital signal processing, and photonics will continue to result in fielding of smaller, more capable coherent jammers.

An issue of growing concern, especially in asymmetric conflict, is the enemy's use of the civilian communication infrastructure such as the mobile phone networks. By 2020 the whole planet will be richly interconnected with communication systems, such as IRIDIUM. These systems may be problematic to destroy or to interfere with. Commanders may, therefore, need to plan on not being able to deny enemy use of the spectrum.

Key Issues Control EM spectrum

- The use of and reliance upon the EM spectrum will dramatically increase in both quantity and type. In view of this, the first requirement is to have an EM spectrum Management System (advanced computer technology).
- To deny enemy use of the EM spectrum specific jamming devices can be delivered by munitions to the enemy's C2 means (MEMS technology).

3.4.5 Impact of Technology on Command and Control (Acquire and communicate information and maintain status, Assess situation, Determine actions required, Direct and co-ordinate subordinate forces, Conduct C2W, Manage public information, Conduct deception in support of operations)

Acquire and communicate information and maintain status, Assess situation, Determine actions required, Direct and co-ordinate subordinate forces

Digitisation of the Battlefield is an initiative currently being researched in many NATO nations which directly addresses most of the sub-components of Command and Control (Acquire and communicate information and maintain status, Assess situation, Determine actions required, Direct and co-ordinate subordinate forces). Digitisation is an extremely complex issue, and could be the subject of a long term scientific study in its own right. Simply stated the aim is:

> *"...to exploit the opportunities offered by advances in digital technology, in the efficient and timely acquisition, processing, distribution and presentation of information, in order to deliver operational benefits throughout the battlespace. The operational benefits will be an increase in operational tempo, lethality and survivability."*

Digitisation is intended to link those battlefield systems which gather, store, process, transmit or use information, in particular sensors and weapons, via appropriate communications and command and control systems. Data fusion, and computer aided decision systems will present such information to the commander in a manner that best suites his needs, which may change according to the phase of battle. Digitisation will also support logistics information and could, in the future, also be used for training and mission rehearsal.

Digitisation also includes intra-system developments best exemplified by programs like the Internal High Speed Data Bus. These efforts link all electrical sub-systems within a vehicle or other platform on a common data stream improving speed, efficiency and maintenance. Further developments will allow these systems sub-systems to be linked to C2 systems. The implication being that not only will the commander and his staff know the location of combat systems but will be able to retrieve data on the "health" of the system. This will improve maintenance and logistic support.

A variety of technologies will be required to deliver battlespace C2 systems including mm wave and optical communications links to satellites, spread spectrum and low probability of intercept waveforms, encryption and multi-level security protocols. The impact of this will be the capability to provide secure high bandwidth information at all parts of the battlefield, linking sensor to shooter in a seamless manner, and providing tactical data and intelligence to all units that require it, even to the level of individual soldiers. Standardised protocols will be essential for efficient multi-national operations and are an important aspect of managing the electromagnetic spectrum. Gallium Arsenide and Indium Phosphide semiconductor devices which are ideally suited to mm wave frequencies are responsible for much of this technology, which is driven by commercial interests such as mobile telephones, digital broadcasting and the Internet. The use of MEMS in passive sensors will allow for low cost access to mm-wave frequencies beyond 95GHz and IR wavelengths beyond12 microns.

In short, Digitisation will give commanders at each level an appropriate and accurate "picture" of the battlefield with a representation of both enemy and friendly forces. Up to date digitised geographic mapping and visualisation, especially in urban terrain, will be of growing importance. This will also support graphical and written orders, situation awareness, calls for fire and certain planning and logistics functions. Decision Support Systems will become mature using AI, virtual environments and imbedded wargames to assist commanders in their decision process.

At the same time as all this, Digitisation must provide for the seamless exchange of information with friendly forces acting as coalition partners, guarantee the

security and integrity of information at all levels and provide reversionary modes in the event of enemy counter C3I attack.

Although primarily dominated by research into computing and communications technologies, Digitisation will also require a significant input from the behavioural sciences to ensure that data is presented in an optimum way for commanders to assimilate it without becoming saturated by "data deluge". Similarly, research into singular and group decision techniques will aid the structuring of information flow in the digitised battlespace.

Conduct Command and Control Warfare

Command and Control Warfare (C2W) integrates all military capabilities in attacking the enemy C2 systems and processes while protecting friendly C2. Relevant techniques and technologies range from the physical destruction of command and control centres through the injection of computer viruses and even extend to the disruption of civilian IT infrastructure, such as international financial systems. As noted already in Chapter 2, there is a real concern that potential adversaries may exploit information warfare as networked information systems become increasingly important to both military and civilian systems, thereby creating additional vulnerabilities.

ESM systems will become more capable, with increased sensitivity, bandwidth and probability of intercept. This requires advanced signal processing and data mining techniques to determine the vital enemy nodes and systems which may be targeted for soft or hard kill. Methods used could include ECM, computer network attack and RF weapons. Decision support tools will propose the optimum attack method and digitisation will ensure a co-ordinated attack. Future operations will possibly demand new techniques to determine the nature of the enemy's C2 processes, culture, and targeting opportunities (Psychological Warfare). Defensive C2W will require consideration of friendly C2 vulnerabilities (which were discussed in Protection) and countermeasures.

Manage Public Information

Managing Public Information is another aspect of Information Warfare, covered already in Chapter 2. A key requirement is for the passage of specific, accurate and timely information to the media which will be facilitated by digitisation and does not compromise operations.

Conduct Deception Operations

By 2020, it would be technically possible to have fleets of robotic decoys for deception operations at minimum casualty risk, but only at an unacceptable cost. Instead the idea of a simple decoy aimed at mimicking the electromagnetic signature of a headquarters or manoeuvring unit is much more plausible, especially in urban environments. Advances in speech processing and synthesis technology are likely to allow the realistic simulation of friendly and enemy personnel over communications links and broadcast media.

Key Issues Command and Control

- Enhanced data management as well as intelligent adaptive data presentation are required to process the ever increasing quantities and types of data (advanced computer technologies)
- Military C2-systems will have to be compatible with specific civil systems to guarantee reliable communications with non-military authorities in the area of responsibility (interfaces and protocols)
- Interoperability of Decision Making processes will be of growing importance in both Joint and Combined Operations (interfaces and protocols)

3.4.6 Impact of Technology on Information and Intelligence (Formulate and direct intelligence effort, Collect information, Process information, Disseminate intelligence and information)

Formulate and Direct Intelligence Effort/Disseminate Intelligence and Information

These sub-components refer to the management of intelligence operations. They have been grouped because they will both benefit from the Digitisation initiative. Collection management systems are an important element in this context. There is a need to properly manage the available collection assets in order to maximise their coverage over the battlespace and to reduce unwanted duplication. For View 2 operations, the use of non-military intelligence sources, such as intelligent Internet scanning and data mining could be very important.

Collect Information

Dramatic increases in computing power and in miniaturisation will lead, by 2020, to an increasing tendency for co-located information gathering and processing so that high-level target information rather than low-level pixel data is what emerges from ISTAR assets. Indeed, vast amounts of data are already being generated from battlefield sensor systems such as: long-range surveillance radars (e.g. ASTOR, JSTARS), satellite based imaging, infra-red and thermal sensors and digitised visual images. At radio frequencies, EW techniques deliver information of comparable importance and complexity from monitoring the enemy's electronic emissions. Each of these will see improvements by 2020, for example room temperature thermal detectors, and ESM systems. The revolutionary change will be both in quality and quantity of data and in the automatic techniques that process, analyse and distribute that information throughout the battlefield. "Sensor to Shooter" is one of the main aims of Digitisation, described under "Command and Control".

One of the more exciting evolutionary changes that will occur will be the ability to see clearly through mist or atmospheric turbulence. Adaptive optics and passive mm wave imaging are the key technologies here. In adaptive optics, miniature sensors and actuators detect deviations in an incoming wavefront and deform the image-forming surface (typically a concave mirror) to compensate in real time. The main advantage of mm waves is that they are not significantly attenuated by water vapour, so that scanning sensors can form near optical quality images in

both day and night using solely the thermal radiation emitted naturally by all objects. Passive milli-metric imaging and active techniques such as ultra-wideband RADAR will also allow imaging through obstacles, which will be especially important in urban operations.

As sensors evolve and become more compact, for example multi-domain smart sensors which will combine visual and IR imagery with active, eye-safe laser radar (LIDAR) in a single package, it will become increasingly easy to deploy them on small platforms, such as UAVs. In the TSW two such systems were studied: a large "Modular UAV" that could carry sensitive sensors or weapons in modular payloads and a small agile "Indoors/Outdoors UAV" intended for operation in urban environments, even capable of flying into and out of buildings. The modular UAV was highly regarded by the military players in the TSW for both View 1 and View 2 scenarios, coming second only to the modular land vehicle, and significantly more valuable than direct and indirect fire assets and conventional reconnaissance platforms. Part of this attractiveness was the level at which the modular UAV was controlled. Unlike strategic surveillance assets such as long-range surveillance radar and satellite systems, the UAV is designed to be under the control of the battlefield commander.

The "Indoors/Outdoors UAV" was specifically designed for urban operations and because of this it was not as highly rated. Nonetheless it possessed several valuable features, including the ability to "perch" and gather surveillance data from appropriate vantage points whilst conserving fuel.

Process Information

The amount of data gathered from a multitude of advanced sensors poses a serious challenge to its translation into useful and timely information. New processing techniques such as improved Data Fusion, multi-spectral Non-Co-operative Target Recognition, paralinguistics, automatic translators and image processors will provide the analyst with high quality processed information.

Key Issues Information and Intelligence

- Intelligent adaptive data presentation is necessary to keep track of all relevant data on the battlefield and not to be overwhelmed by the enormous amount of data available. This will require, *inter alia*, collection management systems and improved data fusion techniques.

3.4.7 *Sustainability (Sustain the Soldier, Sustain the Materiel, Supply and Distribute, Provide Infrastructure Facilities, Provide G5 Support)*

Sustain the Soldier

Future operations will require soldiers to undertake longer periods without rest and to recover more quickly from combat. New drugs and food supplements offer opportunities to enhance performance and resistance of the soldier. Improved integrated clothing systems with personal heating and cooling including miniaturised power supplies will permit operations in extreme environments.

Biotechnology offers the prospect for new diagnostic procedures and treatments against chemical and biological agents. In combination with MEMS health sensors on or possibly implanted within individual soldiers these substances could be accurately and automatically delivered at the precise moment they are needed, thereby dramatically reducing the casualties that might otherwise occur.

One of the great hopes for biotechnology is that it will provide a convenient source of artificial body fluids, in particular blood substitutes that will be readily available on the battlefield, thereby improving the chances of survival for individual soldiers injured in action.

Finally, techniques of automation and robotics, of advanced communications and of sophisticated display techniques will facilitate the concept of Telemedicine, whereby an appropriate expert may give detailed advice on operational procedures to field paramedics from a location anywhere in the world. This will ensure faster, more expert treatment of injured soldiers and will contribute directly to saving lives.

Sustain the Materiel/Supply and Distribute

The expanded spectrum of possible NATO operations poses new demands on logistics. New methods need to be developed taking into account these new expanded responsibilities and the constraints of diminishing defence budgets. Logistic drag is the very antithesis of manoeuvrist doctrine. This is a very complex problem and its solution will require a true systems approach, combining many of the key technologies. For example, lightweight packing materials could be used to reduce the parasitic mass of stores, while the introduction of precision weapons and novel energetic materials should mean that fewer rounds of ammunition are actually required. Hybrid electric power systems could reduce the requirement for fossil fuels. Increases in equipment reliability, standardisation and modular equipment designs will help reduce the demand for replacement parts. Valuable as these advances would be, the key to an efficient, "Just in Time" logistics delivery service will be the digitised battlefield. This will provide a seamless IT infrastructure that can receive input from stores monitoring and health monitoring sensors built into all platforms and link these to a re-supply centre in real time. Stock control systems developed already for industrial use will analyse the data and issue stores where and when needed. Robotics and automation techniques will further help this process and in some cases stores could actually be delivered to appropriate battlefield locations by means of autonomous robot platforms. The impact of this will be to increase the tempo of operations and to permit sustained manoeuverist operations at long-ranges from home.

Provide Infrastructure/Provide G5 support

These areas were not considered in detail in the LO2020 study; however some aspects were covered. Further developments of fast deployable shelters will assist to provide in infrastructure where needed. Technologies such as automatic speech translation and cultural databases are felt to contribute to the G5 support component of capability.

Key Issues Sustainability

- Logistic distribution on the less dense and non-linear battlespace will be a major challenge. Technological developments can help to address the distribution problem by improved system efficiencies, fuel efficiencies, reduced ammunition consumption, weight and size reduction and better planning and tracking systems (new materials, use of COTS logistics systems where possible).
- Increased system reliability will assist in reducing logistic requirements.

3.4.8 *Deployability (Conduct Force Generation, Mount and Deploy the Force, Effect and Maintain Entry into Theatre, Conduct Intra-Theatre Movement, Conduct Training)*

The Navy, Air Force and, increasingly, civilian transportation are responsible for most of the activities comprising Deployability and these are outside the scope of this study.

Conduct Force Generation

The joint Combined Task Force and national contingents will be tailored by use of enhanced analysis tools to support the planning process. The use of Operational Analysis and Simulation will lead, after reviewing a broad range of scenarios, to an optimised force composition.

Mount and Deploy the Force

Mounting the force involves computer-assisted force packaging, advanced wargaming and planning the operation and for rehearsal purposes.

The deployment includes strategic and operational movements. In this respect advanced information technology can be used for planning, directing and monitoring transport assets. Technology can contribute in improving transport capabilities by reducing weight and size of containers and packaging materials, providing advanced navigation systems logistics.

Conduct Intra-Theatre Movement

Demining (already discussed under "mobility"), and decontamination of soils polluted by military activities (unexploded energetic materials, petroleum products and other chemicals) will be made possible by technologies such as in situ bioremediation and other restoration techniques. The development of sensor technologies to detect intrusion (movement detector, seismic sensors...), combined with non-lethal physical barriers and human intervention will improve our abilities to deny access to specific areas without resorting to lethal force. The restoration and maintenance of roads and bridges may be facilitated by the introduction of new materials (such as concrete foam) and improved building techniques. However, this will remain a labour intensive activity.

Conduct Training

There is a need for rapid training techniques for individual and collective training for specialised operations of different types and environments including synthetic mission rehearsals. Advanced computing, and in particular, synthetic environments technologies could offer significant benefits in training. Under the synthetic theatre of war programme (STOW) currently running in several NATO nations, a wide range of training simulators are being linked by means of common protocols so that, for example, a "helicopter pilot" in one country may participate in an exercise involving "tanks" from another with a third source providing a simulated opponent. By 2020, this technology will be greatly advanced and could provide a simulated training environment well suited to practising the collective skills that will be needed in joint and combined operations. This is an area where considerable "spin-in" can be expected from civilian technology, in particular the home entertainment sector. It is likely to become increasingly important as environmental lobbying and budgetary constraints reduce the ability of the military to use outdoor training ranges.

Key Issues Deployability

- Effective force packaging, planning and support systems can assist in tailoring the force (advanced computer technology).
- Transportability has to be improved through reducing the weight and size of systems and the provision of transport management systems (new materials).
- Improved simulation will facilitate training, mission planning and mission rehearsal (synthetic environments).

3.5 SIMULATION BASED ACQUISITION

Although the main purpose of this study is to consider the impact of the technologies and the systems that will use them on the battlefield of 2020, it is appropriate to mention some of the new techniques that will be used to acquire them.

With reducing defence budgets, the increasing need for programme justification and greater financial scrutiny, acquisition processes will have to be efficient and suitably agile to respond to a fast moving technology base. Furthermore, the need to pre-plan product improvements (P3I) in order to rapidly integrate new technologies into fielded systems will become more critical.

As modern systems become more complex, the traditional linear life-cycle model of acquisition management has become too costly (in both time and money) and unresponsive. Although computer-based modelling and simulation tools to improve the acquisition process have been used for years, the cost and complexity of these sophisticated tools were too great to be of practical use to Program Managers (PMs). Recent rapid improvements in IT and in synthetic environments that can support the acquisition process have led to the concept of Simulation-Based Acquisition (SBA).

The objective of SBA is to support PMs in acquiring more cost- and mission-effective systems with enhanced confidence in the supporting acquisition process. An essential goal of SBA is to transform the standard, linear acquisition process into an iterative process that uses simulation to support rapid requirements allocation, concept definition, design, and development and evaluation cycles with virtual prototyping constituting much of the solution in early iterations.

The SBA process can be applied at all stages of the product life cycle:

Concept and development. Use the simulation environment with the soldier-in-the-loop. Iterate the design through development and cost reduction measures. Provide the combined arms, soldier-in-the-loop context through the use of virtual simulators and computer generated forces.

Testing and deployment. As the system matures, going from virtual prototype to real, the simulation environment is used at the system and operational levels to validate performance and identify new needs.

Training. When the software design is near completion, it is exported to build the C2 device itself, and to become the individual and collective training system.

Testing and evaluation. The concept/design can be tested and evaluated continuously in the Virtual Proving Ground. In the virtual prototype and initial design phases, continuous testing of engineering approaches is the main focus. Throughout, all data from continuous testing and evaluation is saved and made available for downstream use, in particular the whole life costs and risk.

3.6 COMPARISON WITH THE US ARMY AFTER NEXT STUDY

The Army After Next (AAN) is a major US study intended to develop a vision of warfare in the long-term future, 2025. It was started in 1996 and concentrates on four areas: geopolitical developments, human and organisational behaviour, the evolution of military art and emerging technologies. Wargames are used extensively in the AAN project to develop thinking in each of these areas. The two key technological themes which the Army After Next has identified are knowledge and speed, themes which are supported in the LO2020 study by 50% of the concepts played in the TSW.

Hybrid Power Systems*
Human Engineering/Cognitive Engineering*
Signature Control*
Protection Schemes for Land Systems*
Advanced Materials*
Alternative Propellants*
Biological and Chemical Protection, Antidotes and Vaccines*
Fuel Efficiency*
Logistics Efficiencies*
** indicates similar technologies in the LO2020 study*

Table 3-3 - AAN Technology Shortlist

Future Groundcraft*
Advanced Airframe
heavy lift
tactical utility lift
Autonomous and semi-autonomous unmanned systems*
Air, Ground, Sensors*
Advanced Fire Support System*
Living Internet* (of unattended ground sensors, UAVs and communication satellites)
** indicates similar systems in the LO2020 study*

Table 3-4 AAN Systems Shortlist

The AAN Technology Shortlist (Table 3-3) and the AAN Systems Shortlist (Table 3-4), are shorter than the corresponding LO2020 lists, but are remarkably similar in content, and thus the outcome of AAN substantially validates the results of this LTSS LO 2020.

3.7 CONCLUSIONS AND RECOMMENDATIONS

Introduction

The military challenges posed in Chapter 2 for land operations in 2020 call for high speed, high mobility and high utility forces that are at the same time well protected and capable of delivering decisive firepower to bear on the enemy. The same forces must be commanded from a system that is capable of assimilating and analysing the vast amount of sensor information that modern ISTAR systems can provide into a common picture of the battlefield that can be communicated rapidly and reliably to all friendly forces. The eleven Critical Technology Areas identified in this chapter are widely applicable and are capable of making the required qualitative step changes in capability that are needed for

this. Of course, we do not claim they represent the totality of technological capability that will be required or that the concepts which embodied them in the TSW are fully optimised prototypes. The conclusion is that, in a world where future prediction is difficult, these broad areas of technology represent fairly "sure bets", and ones which have been recognised independently in a parallel US national study.

Conclusions

One of the main outcomes of the Critical Technology Exercise (CRITECH), the Technology Seminar Wargame (TSW) and the Multi-National Exercise (MNE), has been the identification of a number of emerging technologies, which offer step changes on the battlefield. The first is high power battlefield electrical systems, for propulsion of land vehicles and UAVs, for direct fire weapon and armour systems and in the form of radio frequency electro-magnetic radiation for non-lethal soft-kill weapons. The second is the field of biotechnology that will allow development of new sensors and agents that can accomplish mine detection and clearance. Biotechnology will also contribute in improving the strength, health, efficiency and endurance of the soldier. The third emerging technology is Micro Electrical Mechanical Systems (MEMS). As miniaturized sensors, these are expected to have multiple applications in different areas of military operations, ranging from wide-area monitoring to equipment and personnel monitoring. The fourth emerging technology is Novel Energetic Materials that can provide improved protection as well as new weapons.

Other promising technologies that have been around for quite some time will continue to enhance military capabilities in the 2020 battlespace. A growing interest in all-time situational awareness creates the need of intelligent use of multi-domain smart sensors, and in particular, sensor fusion and data fusion technologies will enable the improved use of sensors, avoiding an overload or data deluge.

A technology that may be poised to deliver benefits is the development and use of high energetic materials that will enable smaller volumes of ammunition or a much greater effect within the same volume.

Considering the breadth of future military operations, armies will have to make equipment fit multiple roles. This will put a premium on versatility, on modular construction and more generally on designing reliable systems that can be upgraded as technology advances or military demands change. This point was well made in the TSW where a general purpose, high performance modular vehicle was rated twice as important as an extremely capable tank simply because it was more versatile.

In the less dense, non-linear battlespace of 2020, the dispersed use of more complex systems will cause ever increasing data traffic. The collection, processing and distribution of these data cause the need for advanced computer based management systems. These systems will enable us to make efficient use of available bandwidth and to fully exploit the capacities of the available assets.

To enable soldiers and units in the 2020 battlespace to make optimal use of all the available assets training and rehearsal will be of the utmost importance.

Simulation and especially the use of synthetic environments will facilitate this. Operational research/operational analysis will enable the optimum use of this synthetic environment for operational planning and staff training.

Whilst it is unlikely that robot warriors will walk on the battlefields of 2020, it is certain that robotics will become more and more important in land platforms and weapon systems, including UAVs. The use of autonomous and automated systems will create additional protection and will help to guard the less dense battlespace.

Although the impact of the technologies described in this chapter can be very great on the military capabilities in the 2020 battlespace, we must realise that foreseeable changes will be evolutionary rather than revolutionary in their character. Besides that, quite a few technologies will be developed for civil applications, as well as for military applications (dual-use). There we will not have to invest in the overall R&D-programme, but rather have to invest in the specific military needs. This is quite different for those technologies where no civil application can be seen within the nearby future. The 11 specific military technologies, out of 34, that were found in the CRITECH Exercise, therefore, will need specific military R&D.

Recommendations

It is axiomatic that the recommendation of any study is that more work needs to be done. This study has established a baseline in terms of technology and its possible applications in future battlefield systems. The next logical step is to carry this forward by establishing additional studies that will:

- review the detailed developments within each of the Critical Technologies to ensure that the perceived military benefits actually do exist,
- review and watch over newly emerging technologies, such as biotechnology, in order that potential military benefits can be identified at the earliest opportunity,
- explore the potential use of technologies in real systems in much greater detail tan was possible in this study in order that the true benefits over legacy systems can be accurately assessed.

To structure this further study, it is recommended that NATO creates a new framework to be called **TECNIC** (the **T**echnical **E**xperimentation **C**ampaign as **N**ATOs **I**nitiative for **C**ooperation).

Within this experimentation campaign goals can be set to meet a yearly demonstration of new technologies within feasible test beds, combined with CAX and FTX exercises of the Nations. [8]

[8] In so doing, NATO would be well advised to consider technological and organisational lessens that could be learned from the US AAN project as well as certain Technology Programs of the European Union (e.g. ESPRIT programmes.)

4. CHAPTER 4 – CONCLUSIONS AND RECOMMENDATIONS

4.1 INTRODUCTION

The aim of this chapter is to merge the salient conclusions and recommendations found throughout the study. Additional conclusions and recommendations are found at the end of Chapters 2 and 3 and Annexes 1 and 2.

4.2 CONCLUSIONS RELATING TO THE NATURE OF THE BATTLESPACE IN 2020

- The battlespace in 2020 will be variable in density, non-linear and more dispersed. It will be cellular in nature, multi-directional and increasingly determined by what is above the battlefield in air and space. The 2020 battlespace is thus the whole of time space and activity.
- Retention of a core ethos based on combat operations is fundamental – a requirement to focus on warfighting, while being able to adapt for other operations.
- Interoperability shortfalls are currently a key weakness and will continue to pose a challenge as NATO becomes enlarged. Priorities for improved interoperability must include harmonisation of doctrine, information systems and communication.
- Information dominance and superiority will remain a key military objective.
- Force structures will need to change in order to exploit technology to the full.
- The most demanding, yet probable environment for conflict is likely to be urban.
- Reduction in logistic drag will be essential for effective military operations in 2020.

4.3 CONCLUSIONS RELATING TO "EMERGING" TECHNOLOGIES

<u>High power battlefield electrical systems</u>

The last time that battlefield propulsive power underwent a major change in modality was when the internal combustion engine replaced the horse. By 2020 electrical or hybrid electrical propulsion systems will be available to replace the internal combustion engine itself as a source of propulsive power.

The benefits will be increased flexibility, reduced vehicle size, reduced thermal and acoustic signatures, and reduced need for fossil fuels. This technology will support the key military objectives of lighter, faster, more agile, stealthier vehicles of all types. This should reduce the maintenance cost and significantly reduce the logistic burden. This is therefore a priority for investment since it supports the overriding need for strategic and operational tempo in the less dense battlespace of 2020.

High power electrical systems will provide lighter-weight active armour protection to improve current levels of protection, which are inadequate for the future threat spectrum.

Finally, this technology will support the fielding of new DEW weapons such as RF and lasers that will contribute to firepower and protection, and significantly reduce logistic burden.

Biotechnology

The probable importance of biotechnology can only be glimpsed at now. Obvious benefits will be in improving the strength, health, efficiency and endurance of the soldier. New sensors for detection of chemical and biological agents and also explosives will be incorporated in miniature devices capable of real time detection. Bioremediation techniques will be available to clear areas polluted by military wastes, including landmines.

MEMS

Micro-Electrical-Mechanical Systems (MEMS) are a logical development of the enormous and continuing advances in nanotechnology, in particular in microprocessing. Crucially, they will be used even more widely in civilian systems, which means that military applications will be able to draw upon an existing manufacturing infrastructure, thereby making MEMS very affordable.

This will provide, for example, a flexible, easily fielded, low cost, ISTAR capability. This will contribute significantly to the vital requirement for layered ISTAR, robust to countermeasures and linked to highly responsive long-range precision attack.

Novel Energetic Materials

Work on tailored explosive materials with potentially orders of magnitude increase in performance has only recently emerged in open publications. This offers the prospects of significantly increasing range and lethality for all weapons using propellants and explosives, which supports the military requirement for flexibility and the massing of effect at longer ranges. It will also support short range applications, particularly the imperative for weapons for urban area conflict. Alternatively, it can reduce logistic burden by decreasing the size of warheads.

4.3.1 ***Conclusions relating to Emerging Technology Applications***

Precision Attack

A major conclusion is that precision attack, which relies on several technologies, will be more prevalent and capable by 2020. Linked to layered ISTAR and BDA, and improvements in lethal and non lethal technologies, it will enable the high priority military requirements of precision, simultaneity, speed of manoeuvre and massing of effects at far greater range. Furthermore, it will blur the distinction between direct and indirect fire and break down the distinctions between combat and combat support arms. Precision attack will significantly reduce logistic demand and collateral damage.

Sensing, Information Fusion and Digitisation

A variety of sensing, computing and communication technologies, particularly the key developments in advanced data fusion and analysis techniques that will carry out intelligent adaptive information processing underpins tempo, the exploitation of space-based assets, information dominance, and control of the EMS, which will be the new high ground. Crucially, it will lead to new ways of conducting operations, for example the exploitation of situational awareness and the management of information in the public arena.

Non-lethal weapons and barriers

There is a clear political imperative for non-lethal weapons and barriers. A variety of candidate technologies have been identified that can contribute to this goal; of these the use of the (emerging) technology of RF directed energy seems particularly promising. However, doctrine is immature with respect to these technologies. It will therefore be necessary to develop it as the technologies of NLW emerge.

Robotics

Robotics systems are, *par excellence*, applications of many technologies, primarily sensing, computing, artificial intelligence and control.

Robotics technologies will offer reductions in manpower and distance soldiers from unnecessary hazards. Both unmanned air vehicles and unmanned land vehicles will be possible. Autonomous unmanned weapon systems could also be deployed but their use is presently limited by ethical and legal considerations.

Simulation and Synthetic Environments

By 2020 computer simulations will be so advanced that synthetic environments will be readily available for a variety of applications, including concept development, doctrine development and performance assessment.

Synthetic environment technology will facilitate training and mission rehearsal, especially for joint and combined operations where field exercises would be prohibitively expensive. Synthetic environments will also be capable of interacting with real platforms and weapons where these have made use of robotics or automation technology in their control systems.

Modular Systems

Modularity is a requirement rather than an application of technology. Modular designs and construction will increase interoperability, increase flexibility and reduce the logistic burden of future systems. It will also be an essential design paradigm if rapid changes in technology are to be inserted and exploited in system upgrades. Simulation, synthetic environments and simulation-based acquisition are the tools that will make modularity feasible.

4.4 RECOMMENDATIONS

In addition to the detailed recommendations listed at the end of Chapters 2 and 3, it is recommended that:

- NATO provides the focus for the development of key technologies with special emphasis on standardisation and interoperability between member nations.
- RTO initiates studies or collaborative research programmes on the above mentioned most promising emerging technologies. These are:

  High power battlefield electrical systems,
  Biotechnology,
  Micro electrical-mechanical systems (MEMS) and
  Novel energetic materials.
- SHAPE considers the conclusions and recommendations of this study for incorporation into the 2000 Defence Planning Cycle.
- SHAPE establishes a NATO Military Working Group to study joint and combined concepts and doctrine with specific emphasis on the View 2 identified in LO2020.
- SHAPE requests follow-on studies similar to LO2020 to keep pace with emerging technological developments and expected changes in the military environment.

1. ANNEX I – NATURE OF THE BATTLESPACE IN 2020

1.1 INTRODUCTION

It is not possible to predict either the time or the place of future conflict; the future security environment will be characterised by variety and uncertainty. However, the root causes of conflict are enduring. They are largely based on emotion, fear, greed, hatred and ambition; coupled with political, economic, religious, ethnic, and nationalistic and environmental interests. In modern developed nations, there will continue to be close political control of the use of force to create stable conditions, as this requires a close connection with a credible political process. This will be set against a background of intense media interest which some might manipulate to support political aims. Amongst other things, these factors will usually generate pressure to confine the conflict to the shortest possible duration and to minimise casualties and environmental damage--these are policy and equipment drivers.

Despite the pressures, the fundamental character of war seems likely to remain unchanged; a contest of wills involving death, terror, bloodshed, destruction and human suffering. For the soldier, warfare will continue to represent a physical and moral challenge that will be at least as great as in the past. He will encounter a combination of extreme danger, rapidly changing circumstances in conditions of chaos and uncertainty, and severe physical demands. The physical and moral character of the soldier, his skills, and the quality of his weapons and equipment will be severely tested.

1.2 AIM

The aim of this annex is to identify and describe the likely nature of the battlespace in 2020 in order to inform the Land Operations 2020 Study.

1.3 BACKGROUND

The uncertain and unpredictable nature of risks, particularly projected out to 2020 and the specific nature of resurgent threats, negates the value of any force designed specifically upon a single threat or current scenario. Forces therefore need to be organised to have the fighting power to conduct all military operations they may have to undertake across the whole spectrum of conflict; that is operations conducted in peace, in operations other than war and in war. In other words, the force must be based upon capability rather than upon the threat. The constituent parts of military capability will form the basis for further work and are not covered in this annex.

During the Cold War the international system was bipolar and alliances were broadly alike in size and in their application of technology. Although terrorism, ethnic unrest, refugee movement and organised crime flourished, military emphasis generally lay towards the more traditional forms of armed conflict between states; they were prepared to engage in unlimited, high intensity conflict.

The end of the Cold War and the dissolution of the Warsaw Pact led to a much reduced likelihood of NATO becoming involved in general war in Europe and to a shift in theatres where NATO members may become involved in conflict. There

has also been a loosening of the constraints on the outbreak of conflict caused by ethnic and nationalist rivalries. Economic and ecological pressures, such as the shortage of potable water, and the proliferation of high technology weapons (including weapons of mass destruction) have heightened local tensions, increased the likelihood of armed conflict and provided the international community with a greater incentive to contain, police, pre-empt or deter hostilities.

There are two additional phenomena. The first is the growing threat from non-state centres of power in forms ranging from religious and ethnic groupings to international business or drug cartels. The second is the increased risk to the home state, including the population, or to national interests abroad posed by non-state actors and rogue states with access to new technologies such as cyberwarfare and weapons of mass destruction. Combatants will tend to differ widely, not only in size, capability and sophistication, but also in perceptions, values and motivation. All this is likely to increase the relative frequency of unfamiliar and less traditional forms of warfare--that is warfare between the forces of the state and the forces of the non-state, and between the forces of states with differing capabilities and motivation.

In attempting to focus a view of the future, two particular trends point the way. First, as long as a majority of the world's nations continue to arm themselves with as much advanced, high technology weapons and equipment as they are able to afford, and while the use of armed force remains feasible in the pursuit of policy, there will continue to be a risk of major regional conflict between similarly well equipped, well trained, mechanised forces. This risk requires long-term planning and continuing investment; competence in it is normally only acquired over time, but may be quickly eroded. This trend will remain the cornerstone of established standing armies and major defence alliances.

The second trend is for state and non-state bodies to resort to criminal and terrorist acts to achieve their purposes because these demand less investment in expensive resources or because they have a different set of moral values yet tend to strike enemies where they are most vulnerable. As the expense of investment in high technology warfighting becomes ever greater, it seems likely that this second trend will assume greater significance. As this type of conflict becomes more common, the extent to which it differs from more conventional forms will influence how NATO adapts. Any such change must take place in full knowledge of the time and effort required to compensate for absence of planning, preparation and investment in conflict of the traditional sort and the high potential risk to NATO of failing to make adequate provision for it.

1.4 THE SPECTRUM OF CONFLICT

Future warfare will not be amenable to tidy classification, as the two trends identified above will evolve together. This will lead to warfare reflecting both trends in varying proportions. Thus in order to simplify the analysis, two speculative views have been chosen to accommodate--in effect a "left and right of arc". This can best be illustrated on a three dimensional diagram shown in figure 1. The diagram provides three axes on which an army can be placed relative to its technology level, professionalism and training and finally its size.

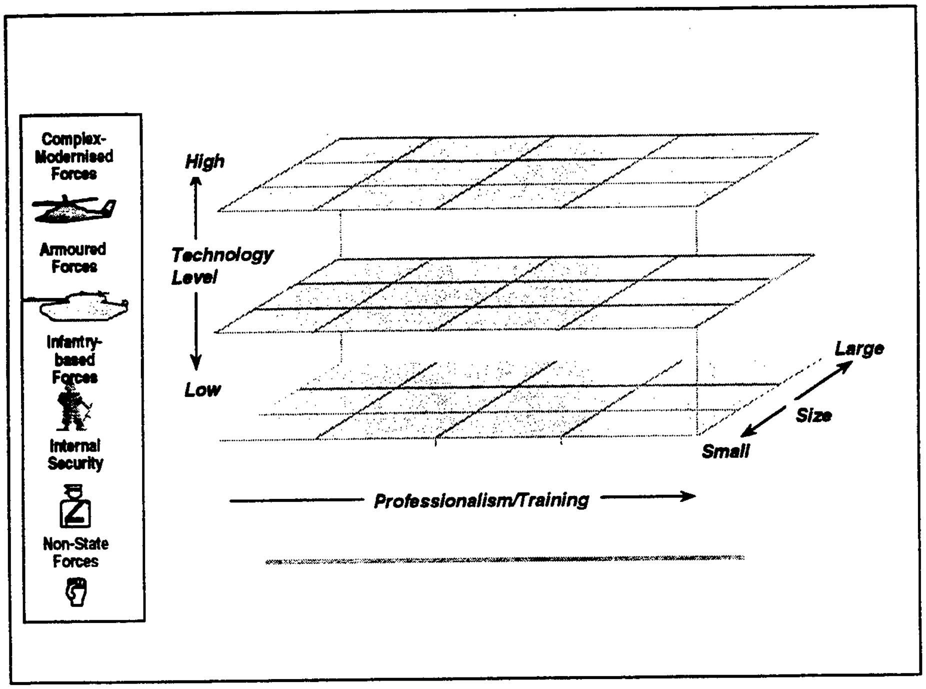

Figure 1-1 - 3 Dimensional Classification Scheme

From this, one can illustrate a variety of future conflicts. However, there are two views that become quickly apparent. These are the symmetric or near mirror conflicts in terms of forces, and the asymmetric conflict both of which are illustrated in figure 2.

View 1 will represent warfare between two modern, well equipped, well trained, mechanised forces while View 2 will represent a modern force opposed by organisations that do not necessarily represent states nor structured in the manner of most armies. These two views contain much that is familiar. Already many armies have acquired the capacity to take part in both. What may need to change is the relative importance accorded to each of them in the future; the balance to be struck in providing for both sorts of conflict will be central to future work.

Overlaid on both these views is the increased sophistication and importance of *information warfare*[1]. As Western nations increasingly exploit, and come to rely on, information technology, opportunities and vulnerabilities will materialise. While this form of warfare will be orchestrated at the strategic level, will be joint and most likely combined, it will manifest itself at the operational and tactical levels as information operations in which all military capabilities are synchronised to attack the enemy's cohesion and defend one's own.

[1] Alvin and Heidi Tofler, *War and Anti-War - Survival at the Dawn of the 21st Century*, Little, Brown and Company, 1993.

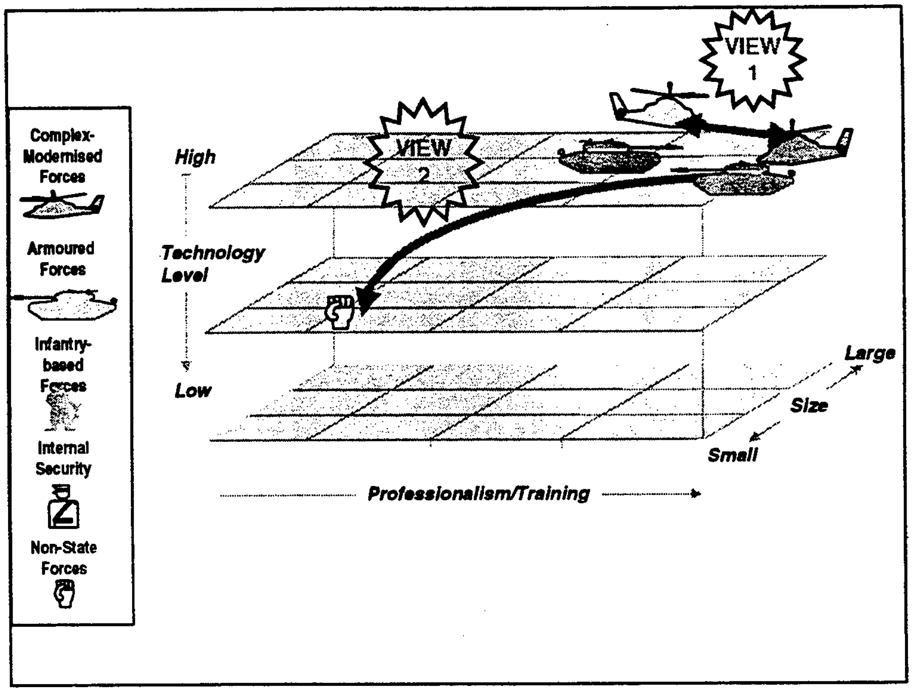

Figure 1-2 - Two Views of Future Conflicts

As has already been suggested, the nature of the operational environment in 2020, particularly in terms of warfighting, will be more complex and involve a more multi-dimensional perspective than the term " battlefield" has hitherto embraced. For this reason the term "battlespace"[2] is used in the study. It reflects not only the conventional three-dimensional notion of the battlespace, but also the increasing influence of the electromagnetic spectrum in conflict. For this reason, amongst others, while many of the aspects and implications of future battlespace are reflected throughout the paper the notion of "battlespace" will be implicit rather than prescriptive in the work that follows.

1.5 VIEW 1

1.5.1 Characteristics

For most NATO forces, the trend in future operations is expeditionary in nature, conducted in uncertain circumstances and over unprepared ground without the in-place logistic infrastructure and level of host nation support foreseen in the Cold War. This will have implications for the balance between strategic and tactical mobility. Alliance or coalition warfare will be the norm and joint operations inevitable; indeed the land and air components[3] will be even more closely linked than they are today. Furthermore, financial and environmental considerations will continue to constrain the proportion of the force that can be

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[2] Battlespace is a physical volume, which includes the moral dimension that expands or contracts in relation to the ability to acquire and engage the enemy. It includes the breadth, depth and height in which the commander positions and moves assets over time. Battlespace is not assigned by a higher commander and extends beyond the commanders *area of operation*.

[3] Maritime and amphibious components, where appropriate.

maintained at high readiness states. In addition, there will be a need to balance the equipment, organisation and structure of these forces with deployability, sustainability and readiness.

Compared to the Cold War era, View 1 is likely to be characterised by the deployment of fewer, but more capable weapon platforms. They will have been procured over lengthy periods and they will be designed from the outset to remain operational longer. Units and formations will possess increased combat power and will be more agile. The proliferation of military technology will produce hybrid equipment with considerable capability that will be available to more countries. This will be made possible by inventions and advances that will provide more effective means of acquiring and engaging the enemy. Chief amongst these will be rapid advances in digital technology[4]. More attention will be paid to the domination of the electromagnetic spectrum.

A combination of small forces, increasingly capable sensors and long range precision effects will further increase the trend towards dispersion in a less dense battlefield and throughout the battlespace and towards higher tactical mobility. Ill defined dividing lines between opposing forces and a less clear distinction between front and rear, or land and air will increase the need for situational awareness and combat identification. Technology will increasingly allow for fighting more remotely and over longer ranges, engaging C3I targets in addition to platforms; however, the capability to close with the enemy and to take and hold ground will continue to be fundamental. Operations will be day and night and all weather, often conducted under extreme climatic and terrain conditions. This will continue to demand ground forces that can provide endurance and presence. The probability of conflict in urban areas will increase. Forces must be capable of engaging in and from the urban environment where lightly equipped forces may have an advantage over armoured opponents, communications and situational awareness are problematical, civilian involvement is high, and the effects of emerging technologies may be hard to predict. Indeed, forces should be capable of operating in and from all environments.

Immediately after cessation of hostilities, there may be a period when a return to warfighting is possible. During this period the emphasis will be on maintaining a balanced posture with the potential to respond or prevent aggression. A high premium will be placed on ISTAR assets as well as rapid and effective action.

As in the past, forces will become involved in post-conflict activities including peace support, humanitarian relief, battlefield clearance, demobilisation operations, and the restoration of public utilities and civil administration in concert with other agencies. The speed with which this post-conflict activity can be achieved may determine the duration and therefore expense of the operation. Any success in stabilising a situation may require a long-term military commitment that may shade into the conditions described in View 2 conflict below. Fundamental to this view of conflict, however, is that conflict will be a complex, shifting amalgam of View 1 and View 2. The skills and force-mixes required for post-conflict activities may not be those that have been involved in the warfighting. View 1 will place the greatest demands on the soldier at all

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[4] Information technology is the most obvious example, but one must not ignore advances, for example, in material and biological technologies.

levels. Many of these demands will be those which have typified the human implications of conflict for centuries. There may be others that will be new or at least of greater importance in the future.

1.6 VIEW 2

1.6.1 Characteristics

In View 2, NATO´s modern, high technology forces will be opposed by armed forces directed by social entities which are not necessarily states, conducted by organisations that are not necessarily armies and fought by people who are not necessarily soldiers in the conventional sense of the term (to be referred as "irregular forces"). It is the nature of such conflicts that they may well have begun before national and alliance forces have deployed; the desired end-state and the criteria for victory may be unclear. In such a conflict, the battlespace will also be extended with forces vulnerable to attack, not only in the theatre of conflict, but throughout the lines of communication, including the home state. Such attacks will not be confined to military targets but could include governmental institutions, the civilian population, economic and cultural centres and other high-profile actions designed to attract media attention.

1.6.2 Irregular Forces

Irregular forces may be associated with political movements, criminal enterprises, drug cartels, religious sects and pressure groups. Some governments may find expediency in pursuing their interests through irregular forces. As the cost of deploying regular forces increases, more developed states will also find that they can only afford an irregular form of force.

The aims of those directing irregular forces will often have an anarchic and unpredictable nature. It can be expected that irregular forces will operate with different moral or political constraints; indeed, it will be the very lack of constraint that gives irregular forces their strength. They will be armed and equipped from an inventory encompassing the entire range of military capability[5] including weapons of mass destruction, with the probable exception of very high value frontier technology assets. At the heavier end of the scale top-quality weapons, in terms of precision, potency and range, will be widely available. The blend of low technology weapons with specific high technology *off the shelf* systems, which may have primarily civilian application, will enhance the effectiveness of irregular forces particularly where they choose to operate against non military targets. Overall, it is considered that the prevalence weapons of mass destruction, and the relative ease of delivery of means such as biological and chemical agents, render their use more likely. This will have impact at each of the tactical, operational and strategic levels of operation. This probability is increased by the concept of *plausible deniability*, which serves to deny nations states a clearly identifiable target, and which threatens the credibility of nuclear deterrence. This underlines the need for a new impetus in protection and detection technologies. It also suggests new arrangements for co-ordination

[5] E.g. GPS and improvised cruise missiles, cellular telephones, access to the Internet and commercial chemicals.

amongst the security and military agencies of member nations.

Irregular forces will be prepared to wage a protracted conflict in order to outlast NATO´s commitment. Targets will be people and the civil infrastructure, as well as military personnel and systems. The distinction between civilian and soldier will be blurred, often as a deliberate tactic. Irregular forces will primarily engage not in battles, but in skirmishes, raids, ambushes, bombings, hostage-taking and massacres. Terror will be a central part of their strategy; one goal may be the co-operation and connivance of the target population, another may be to separate the population from its authorities. In addition, they can be expected to attack computer networks, information systems and data banks with technology widely and cheaply available on the open market.

Urban warfare is likely to be more attractive to the View 2 adversary, given that 70 % of the world´s population will live within urban areas, and where the presence of civilian population and infrastructure will make it difficult to fight irregular forces. Thus although the manoeuvrist approach endures, changes in doctrine tactics, structures, techniques and procedures, training and equipment will be required.

Success in the moral dimension will be crucial--creating and shaping the environment for operations. Winning the hearts and minds of the civilian population is likely to be an imperative in View 2 conflict. A vital influence in moulding this environment will be the inevitably close interest taken by the news media. Military action will need to take into account civil authorities (police forces and security services), non-governmental organisations and governments. The relationships between these organisations and the application of military force are likely to become more complex. C2 and force-mix will need to adapt and be capable of interoperating accordingly. View 2 will not only present the soldier with the moral challenges of View 1, but also with a greater degree of autonomy, with wider implication for the actions of individuals. This will in turn present different intellectual and training challenges and requirements.

1.7 CONCLUSIONS

- The two views of future conflict are not intended to be mutually exclusive, nor do they discount other views. They are, rather, two illustrative but generic scenarios which will enable their use to address the capabilities required to engage in warfighting and therefore to produce a series of capability and equipment issues which will provide the technological experts with guidance on what technologies may be appropriate to invest in to equip land forces for 2020.
- The process of describing two such pure and dissimilar views of future conflict is merely a first step on the path to deciding on an Alliance structure capable of facing enemies in the next century. The probability is that future conflict will not fall wholly either into one category or the other. Elements of both will be found in varying degrees in most future conflicts.

- It follows that future NATO component land forces must be versatile in their capabilities and ready to do all these things. Also, assuming that funding will reduce, forces will not be able to maintain the full span of capabilities at a high state of readiness. This underlines the requirement for organisations and equipment to have utility in both Views.
- Participation in NATO operations could increase the risk to home states from terrorist acts, in particular WMD.
- Information operations will be of increasing importance.
- The balance between strategic and tactical mobility will be significantly affected by the availability of host nation support in campaign operations.

2. ANNEX II -Land Operations 2020 Force Description

2.1 AIM

The aim of this annex is to identify the types of land forces needed by NATO in 2020 in order to provide guidance for future force planning and equipment development within the Alliance.

2.1.1 Scope

This annex makes a number of assumptions about the Alliance, assesses the key determinants which are most likely to influence the shape of NATO forces and identifies structural drivers on which to base future work. This annex recognises that there are many unpredictable and external factors affecting the types of land forces 2020. It is therefore impossible to elaborate with any degree of certainty the detail of the types of future forces. The most useful approach is to identify the broad drivers that will determine the overall shape and design, rather than to develop a design that will be certain to change.

2.2 ASSUMPTIONS

Collective defence will remain paramount to all NATO military requirements. However, NATO will contribute to other military operations.

The force structure will be consistent with the Nature of the Battlespace in 2020 as described in Annex I.

There will remain differences in the pace and degree of modernisation between of the member states.

2.3 KEY DETERMINANTS

2.3.1 Areas of Deployment

The Alliance has to maintain versatile forces that can cover all types of missions required throughout its area of responsibility and beyond in accordance with NATO´s future mission spectrum. Thus, NATO force structures for the year 2020 will have to take into account areas of deployment in extremes of climate, terrain and infrastructure. Deployment may also be at longer distance.

2.3.2 Power Projection

Future forces must be capable of power projection to protect NATO´s interests and preserve stability. Forces must be able to perform missions ranging from humanitarian operations, preventing or stopping small-scale conflicts, and reversing large-scale regional aggression.

2.3.3 Combined Operations

In 2020 NATO operations will continue to be combined. As a priority, member nations must therefore ensure that they can contribute to such operations. Key to

this is likely to be factors such as standardisation, interoperability of ways and means and structures capable of task organising accordingly. This must take into account the different technological levels of the member nations.

2.3.4 ***Joint Operations***

The conditions of the battlespace demand integrated ISTAR (including BDA), increased tempo and simultaneity of combined and joint forces. This will require much greater integration of the land, air and sea components, which in turn may lead to changes in structure and ways of command at all levels. This is a key driver for digitisation.

2.3.5 ***Interagency Operations***

It is likely that the interaction with non-military agencies and civil authorities will become increasingly important feature of operations that fall short of View 1. Although technology is unlikely to have a significant impact on this requirement, it will influence future structures, C2 arrangements and training.

2.3.6 ***Burden Sharing and Role Specialisation***

The desire to demonstrate Alliance solidarity and the increasing number of member states place challenges to coherence and unity of command. Furthermore, differences in equipment capabilities, the declining budgets and the globalisation of defence industry will demand greater commitment to burden sharing, standardisation and role specialisation.

2.3.7 ***Responsiveness***

Since high readiness is expensive, and while the likelihood of a full scale conflict is assessed to be low, NATO can plan for tiered readiness to respond to varying degrees and nature of threat. NATO must recognise that the contribution from member nations will be different due to the changing balance between conscript, reserve and professional forces. Overall, the emphasis for the highest readiness is likely to be for highly trained, light, rapidly deployable forces but with the highest possible firepower and protection. These are key drivers for technology. Future forces structures will also depend on the available military preparation time constituting the requirements for regeneration and reconstitution.

2.4 STRUCTURAL DRIVERS

2.4.1 ***Doctrine***

The manner in which NATO forces will conduct operations in 2020, characterised by speed of manoeuvre and operational tempo, decentralised execution, high lethality, and increased complexity, should be underpinned by doctrine. Doctrine is pervasive and will remain a primary structural driver for the types of forces in 2020, but has to be evolved in accordance with the development of technology. The doctrinal ethos of NATO is embodied by the manoeuvrist approach – the

essence being to avoid an opponent's strengths and attack his weaknesses. This encompasses political, military and public support to defeat an adversary through attacking his will to fight and the cohesion of his force. In this regard, it is incumbent upon future NATO land forces to ensure that they train, structure, organise and equip in a manner that is consistent with the manoeuvrist approach. The development of doctrine must accommodate an accelerating pace of change.

2.4.2 ***Human Factors***

Meeting the technical and intellectual demands of the 2020 battlespace will require soldiers of high quality. Essential, will be the maintenance of core values, such as selflessness, mental and physical toughness, and ability to accept responsibility, judgement and initiative. However, there will be need to be a significant growth in the number of soldiers possessing the aptitude for information skills upon entry. Additionally, the growing complexity of equipment and economic pressures may place an increased level of reliance upon contractor support in the battlespace, which may impose major changes on existing support structures, the employment categories and terms of service of military personnel. Growth in the sophistication of operations, the multiplication of new skills, and the rising technical complexity of many functions, may drive member nations' land forces towards greater degrees of specialisation amongst their personnel. This may conflict with the need for generalists and underpins the demand for greater precision in personnel management.

2.4.3 ***Training***

Training regimes will need to adjust emphasis to account for changes in missions and threats, such as urban operations, WMD, information operations, homeland defence and extended force protection during deployment. Routine and on-going peacetime activities will create conflicting demands on resources that will necessitate greater efficiencies in training structures through techniques such as just-in-time, on-call, and en-route training and rehearsal capabilities to help forces to prepare for short-notice commitments. Exploitation of information technologies, synthetic environments and advanced training processes may assist the better integration of individual and collective training. The joint and combined nature of the battlespace places greater emphasis on training in joint, combined and interagency operations. This may demand changes to the infrastructure and manner of training in peacetime, such as the development of common doctrines, tactics, techniques and procedures for inter and intra-service force-generation.

2.4.4 ***Modularity***

Modularity may provide efficiencies in combat power and sustainability for a variety of potential missions in 2020. It may be a significant feature of future force design. Modularity allows increased flexibility in force packaging and task organising and a degree of self-sustainment, particularly in decentralised operations. However, modularity must rest upon habitual relationships that build

trust, confidence and cohesion. The friction of combined operations, which militates against tempo, will also dictate the limits to which modularity can be introduced into a multinational force framework. Essential, will be better institutional cohesion amongst member nations to imbue a sense of teamwork to underpin the inevitable creation of ad-hoc force structures.

2.4.5 ***Flexibility***

Flexibility will remain an enduring principle. Essential, will be the type of forces that can adapt to meet the changing conditions of the battlespace, respond to technological or tactical surprise, and operate with Alliance forces with differing capabilities. Maintaining such flexibility will require continuous organisational testing and training. Joint-force packaging will need to be flexible at both the national and international levels and will demand a broad mix of capabilities to be maintained both within and amongst member nations, in order to provide a commensurate flexibility in policy options.

2.4.6 ***Utility***

Demands for NATO forces to have maximum utility at minimum cost – to be highly usable across the spectrum of conflict – will intensify in the presence of ever-increasing demands upon public finances, and in the face of a wider range of missions. More flexible structures that are capable of task-organising more readily, increased degrees of peacetime modularity, and multi-rolling of core capabilities at more appropriate levels of readiness may be required to enhance the utility of military systems. The drive for utility underpins the requirement for more versatile systems, and for technologies such as advanced networked simulation techniques for cheaper but more flexibles combined training.

2.4.7 ***Technology***

The detailed implications of technology on the types of forces will take time to emerge and, self-evidently, must be the subject of continuous follow-on work. However, initial indicators suggest the following broad range of characteristics:

Significant increases in speed, at the tactical, operational and strategic levels, to overcome the strength of a knowledge and precision-based defence.

Lighter, more efficient weapons and munitions.

Propensity of more agile, better protected and modular ground manoeuvre and ground support platforms.

Reduced mass of combat service support to increase tempo.

Migration of joint structures and procedures, particularly in the areas of C2, logistics, intelligence, planning and analysis.

New structures to support UAV, enhanced sensor and space-based capabilities.

Importance of air-manoeuvre embedded into land components, including integral fire power, ISTAR and support capabilities.

Growth in specialist information operation capabilities.

Blurring of the distinction between direct fire and indirect fire organisations and systems enabled by range, precision and speed of engagement.

2.5 CONCLUSIONS

- The need for change in force structure is inescapable and flows from the changing security environment, the increased likelihood of multi-national and multi-agency operations, the impact of emerging technology, the evolving nature of conflict and the continuing pressure on resources.
- Future NATO force structure must be capable of conducting joint and combined operations as well as operations involving other agencies. Therefore military organisations must be able to adapt to various contingencies across the full spectrum of conflict.
- NATO 2020 land forces must be rapidly deployable, with capable ISTAR, highly survivable, lethal, agile, mobile, flexible in design, and equipped and prepared for high intensity conflict and flexible enough to respond to operations other than war. This demands the capability to assemble rapidly, deploy, and employ a force based on flexible, versatile organisations.
- Leadership and human values remain paramount. Technology must support the soldier without overloading him mentally and physically. Meeting the technical and intellectual demands of the 2020 battlespace will require soldiers of high quality.
- Information superiority and digitisation will improve knowledge and speed. This may result in new staff functions and organisations to exploit these advances.
- Organisations at lower levels may need to be able to perform joint and combined functions previously conducted at higher levels. In essence, functions at all levels will need to be re-evaluated.
- Combined forces of Alliance members should have compatible agility and adaptability to be able to achieve superior tempo. There will remain differences in the pace and degree of modernisation between the member states emphasising the need for standardisation between legacy and new systems.
- Protection against the full spectrum of attacks, including weapons of mass destruction must be incorporated across the NATO force structure.

3. ANNEX III- THE DERIVATION OF FORCE COMPONENTS OF CAPABILITY FROM THE NATURE OF THE BATTLEFIELD

	REQUIREMENT	REMARKS
CC1 – MANOEUVRE		
CC1.1 - CONDUCT MOVE-MENT	Improved situational awareness. High speed multi-purpose tactical and logistic platforms. - improved Mapping products, - improved Aids to navigation, - improved Route finding and proving products, - improved Automatic position locating and reporting, - improved Mapping products for urban areas. Need for tactical and operational transportation capability.	*The ability to move forces throughout the entire battlespace as quickly and accurately as possible.*
CC1.2 - CONDUCT DIRECT FIRE	Rapidly acquire and engage multiple targets at short, medium and long ranges. Precision engagement of hard and soft targets at short, medium and long ranges. Minimise collateral damage. 24 hour all weather capability and avoiding fratricide. Capability to engage personnel and equipment with Non Lethal Weapons (NLW).	
CC1.3 - PROVIDE MOBILITY	Enhanced tactical mobility. Provide technical means to rapidly cross man-made and natural obstacles.	*Need to identify and counter new or novel anti-mobility devices that may be on the battlefield in 2020.*
CC1.4 - PROVIDE COUNTER MOBILITY	Create brilliant, lethal and/or non lethal obstacles in all terrain.	*The rapid creation of obstacles to defeat enemy manoeuvre, even when apparent to him.*

CC1.5 - CONTROL AREA OF INFLU-ENCE	24 hour all weather ISTAR. Rapid construction of field defences. Long range precision indirect and direct fire. Lethal and Non Lethal denial systems.	*The key requirement of land operations of a manoeuvrist nature is to deny those areas to the enemy, which give him advantage while protecting those areas which give advantage to friendly forces.*
CC2 - FIRE SUPPORT		
CC2.1 - PROCESS GROUND TARGETS	Allocate, co-ordinate and control appropriate fire support including future target data storage. Fuse ISTAR output rapidly. Real time, command-filtered sensor to shooter links. Fratricide reduction including combat identification. Conduct rapid, accurate BDA.	*The ability to identify high value assets early, pass timely targeting information. And to allocate, co-ordinate and control appropriate fire support systems will be critical.*
CC2.2 - ENGAGE GROUND TARGETS	Conduct precision C2W. Conduct precision fire at long range. Fight from air and support operations from space. Mass and switch ground fires rapidly. Engage with NLW. Minimise collateral damage.	*Key among the fire support capabilities will be the need to effectively link sensors and shooters as well as outranging enemy long-range indirect fire systems.*

CC3 – PROTECTION		
CC3.1 - PROVIDE AIR DEFENCE	Integrate all air, maritime, space & land AD systems, providing a common, joint air picture of the battlespace. Provide early warning, nullify or reduce the effectiveness of attack /surveillance by manned and unmanned airborne platforms or missiles. 24 hour all weather warning of air attack. Comprehensive air/missile defence during theatre entry operations.	*More capable air systems will increase. Demands for more capable air defence with credible anti fratricide systems to protect the freedom of action of ground manoeuvre forces.*
CC3.2 - PROVIDE PROTEC-TION	Robust anti fratricide combat ID/IFF. Adaptive, smart, active and passive protection systems for military/civilian personnel, installations and vehicles. Provide protection for personnel, equipment, and systems in order to reduce, or avoid the effects of enemy actions including: protecting individuals and systems from fires, measures to protect electronic systems, protective structures for forces and facilities, protective measures for formations, units, sensors and individuals, the removal of battlefield hazards.	*Smart protection is required to improve the survivability of weapons platforms and personnel while reducing the weight burden and increasing mobility.*
CC3.3 - PROVIDE SECURITY	Passive early warning linked to reactive counter-measures. Non-lethal security systems in urban areas and areas of high population. Collect and provide information on the threat. Add-on protection systems for civilian installations.	*The tempo of future operations will provide less time to identify incoming threat systems and smaller forces will increase this pressure while offering fewer options to deal with them in a timely manner.*

CC3.4 - PROVIDE NBC PROTEC-TION	Accurate, timely warning of NBC hazards. Adaptive broad spectrum protection. Rapidly deployable and employable decontamination systems for NBC hazards. Provide pre and post attack treatment for NBC threats.	*A wide range of NBC detection decontamination and treatment systems will be essential.*
CC4 - CONTROL EM SPECTRUM		
CC4.1 – MANAGE OWN USE OF EM SPECTRUM	Joint and combined management of EMS. EMS management system taking account of geographical, urban and fratricide factors.	*EMS reconnaissance and management tools which maximise utility of EMS to friendly forces and most effectively deny same to the enemy.*
CC4.2 - ASSESS DEGREE OF CONTROL REQUIRED (ENEMY + OWN)	Detection and analysis of all EM emissions including lasers. Protection for EO systems. Development of EO attack systems.	*There will be an increasing need for ElectroOptic (EO) attack systems and EO systems protection.*
CC4.3 - DENY ENEMY USE OF SPECTRUM	Frequency agile deception techniques which can be used selectively. Systems which deny the enemy use of EMS, throughout all Wavebands.	*Resilience and redundancy in communications bearers, processing and power sources will be essential.*

CC5 - COMMAND AND CONTROL

CC5.1 - ACQUIRE AND COMMUNICATE INFORMATION AND MAINTAIN STATUS	Joint and combined C4I. Timely and appropriate information dissemination within all levels of command in a joint and combined environment in agreed formats. Acquisition of information on mission, enemy forces, friendly troops, terrain and weather for the commander. Integrate data fusion into the intelligence cycle.	*This will be the principal enabler for forces to set tempo. One major difficulty to overcome will be NATO interoperability.*
CC5.2 - ASSESS SITUATION	Rapidly collect and analyse data from various media. Disseminate in intelligible format appropriate to the level of command.	*Prevention of information overload will be the key to success. The right information in the right place at the right time.*
CC5.3 – DETERMINE ACTIONS REQUIRED	Dynamic and flexible planning and decision support capability for all commanders and specialist staffs. Conduct automated risk assessment of plans.	*Accurate assessment of likely/possible enemy actions/reactions to own decisions will reduce incidence of the unexpected causing degradation of performance through shock or surprise.*
CC5.4 - DIRECT AND COORDINATE SUBORDINATE FORCES	Battle Management System allowing effective direction, in real-time, to subordinate forces over long distances in a hostile electromagnetic environment.	*Another aspect of tempo is the ability to transition from one activity to another in the shortest possible time.*

CC5.5 - CONDUCT COMMAND AND CONTROL WARFARE	Ability to detect, identify and attack enemy C2 through co-ordinated use of all available assets whilst maintaining own security and OPSEC from attack. Capability to protect and defend own C2 , recognise and understand vulnerabilities and identify countermeasures.	*The disruption of enemy C2 systems produces dislocation and reduction in tempo thereby systematically reducing the ability to react to friendly force actions.*
CC5.6 **MANAGE PUBLIC INFORMA-TION**	Proactive information handling and presentational capability that provides the commander with instantly releasable information to support land force current and future operations. Co-ordinate the timely release of information and imagery to the media and the force.	*By ensuring that friendly actions are quickly and accurately reported by the media, the ability of the enemy to reinforce his moral standpoint can be reduced.*
CC5.7 - CONDUCT DECEP-TION OPERA-TION	Decoy and camouflage capabilities that are effective throughout the EMS to protect our high value assets. Effective counter-sensor operations. Conduct psychological operations. Mount complex deception operations using the entire EMS and virtual and false signatures, reinforcing enemy commander's expectations of the likely friendly course of action.	*The use of deception can keep the enemy off balance and concentrating on less important events while the key vulnerabilities are isolated, exploited and attacked.*

CC6 - INFORMATION AND INTELLIGENCE		
CC6.1 – FORMULATE AND DIRECT INTELLIGENCE EFFORT	Application of artificial intelligence, data fusion and sensors management to automate: -joint planning, identification and execution of the commanders' -information requirements. -matching of appropriate sensors to agencies/tasks.	*The optimum management of sensors and sources focused to expose the key vulnerabilities of the enemy will provide opportunities for the commander to seize and retain the initiative.*
CC6.2 - COLLECT INFORMATION	Collect real- time all-source information in all conditions throughout the battlespace. Detect and monitor all weapons of mass destruction in all weathers throughout the battle space.	
CC6.3 - PROCESS INFORMATION	Automated data management, AI and fusion capability to give: - Assessment and analysis of enemy capabilities. - Assessment and analysis of enemy intentions in real-time.	*Extracting the important intelligence from a constantly changing mass to focus on areas of enemy weakness and exploit them.*
CC6.4 – DISSEMINATE INTELLIGENCE AND INFORMATION	Selectively and disseminate rapidly data from various media. Timely provision of intelligence and information to commanders and staffs in an appropriate and digestible format.	*The timely dissemination of information and intelligence in appropriate formats increases tempo and enables the commander to get inside the enemy decision cycle.*

CC7 - SUSTAINABILITY		
CC7.1 - SUSTAIN THE SOLDIER	Increase physical and psychological endurance of the soldier. Rapid acclimatisation when moving from one environment to another. Improved medical and hygiene support at all levels capable of coping with high casualty levels and complicated procedures. Lightweight, palatable, easily prepared nutritious rations that take account of the requirements of varied cultures. Provision of potable drinking water in all environments. Rapid, cheap, accessible controllable communications between soldiers and their families.	*The moral and physical sustainment of the soldier during periods of stress and danger, often for protracted periods, is a key element in producing the moral component of fighting power.*
CC7.2 SUSTAIN THE MATERIAL	Increase RAM-D for all equipment, allowing reduction of logistic effort through self-diagnostic, self-preservation, self-prognostic and self-repairing systems including the use of novel materials. Integral power sources without the need for the provision of external fuel. Reduce munitions bulk. Extend shelf life and maintenance free long term storage. Enhance and automate BDR.	*The materiel support of agile and mobile formations across large distances will be a prerequisite of operations on future battlefields.*
CC7.3 - SUPPLY AND DISTRI-BUTE	Low manpower, low maintenance, "just in time" supply with automated logistic tracking and distribution system matched to the mobility requirements of the operation, minimising intermediate handling and providing full visibility of stocks available to the operation. The system should have built-in redundancy. It must be sufficiently flexible to cope with multi-national deployments from a variety of alliance partners and should take account of national, industrial and political concerns.	*Stocks of materiel must be kept to a minimum to reduce wasted effort, cost and minimise logistic drag by matching the capacity, mobility and protection demands of the force without constraining operations.*

CC7.4 - PROVIDE INFRA-STRUC-TURE FACILITIES	Capability to repair and maintain natural and existing infrastructure to sustain own forces and the provision of facilities, including roads and airfields, where they are non-existent, rapidly.	*Forces operating on the future battlefield must be able to maintain acceptable levels of infrastructure, especially in protracted operations, and provide facilities where none exist for the rapid support of formations in all operations of war.*
CC7.5 - PROVIDE G5 SUPPORT	Automatic translation facilities. Cultural data base.	*The overcoming of language and cultural barriers will be critical in providing in place support to operations.*
CC8 - DEPLOYABILITY		
CC8.1 - CONDUCT FORCE GENERA-TION	Joint and combined automated tool and database that: - analyses projected operations, - defines the requirement for forces and their capabilities, - recommends options for force packages related to the stated availability of national forces assigned to NATO. *(*This capability must allow the integration of non-military agencies into the force.*)*	*Smaller forces will require more accurate force packaging to provide appropriate responses to situations as they develop.*

CC8.2 - MOUNT AND DEPLOY THE FORCE	High volume strategic lift capable of rapidly deploying world wide. Identify and monitor the status of declared civilian strategic lift capacity available to alliance partners in advance to facilitate the mounting of operations.	*It will be important to match strategic lift capabilities to appropriate early entry capabilities and rapidly deployable, high readiness port and airport handling facilities.*
CC8.3 - EFFECT AND MAINTAIN ENTRY INTO THEATRE	Rapidly deployable modular systems to enhance or replace SPOD and APOD facilities. Rapid joint and combined expeditionary capability to establish and hold points of entry by force.	*Early entry forces must be able to secure the lodgement for appropriate lengths of time to allow the build up of heavier forces. In the absence of basic infrastructure capable of dealing with rapid force build up, these must be established during the initial phases of operations.*

CC8.4 - CONDUCT INTRA-THEATRE MOVE-MENT	Rapidly deployable non-tactical gap-crossing capability. Techniques for the large scale. decontamination of areas polluted by military activities and the consequences of operations, including mine fields. Non-lethal area denial systems to prevent access to routes and control areas.	*The maintenance of routes throughout the theatre of operations will be critical to the achievement of tempo and simultaneity. The normalisation of areas affected by conflicts will be one key to the prevention of recurring hostilities and minimise risks during post operations.*
CC8.5 - CONDUCT TRAINING	Innovative and rapid training techniques to facilitate training of mobilisation forces/reservists. Capability for individual collective and staff training for specialised operations of different types and different environments including synthetic mission rehearsal. Training of commanders and principal staff to prepare them for an operation with a short warning time. Need to maintain View 1 skills in a View 2 environment.	*All necessary facilities will be required to prepare the training organisation and to train individual reservists. The maintenance of primary military skills during and after protracted View 2 conflicts will be critical.*

4. ANNEX IV – UNDERPINNING TECHNOLOGIES

Annex IV to the Study Report on Land Operations 2020 provides an overview of the technologies which underpin the eleven broad technology areas identified as those which are most likely to make a significant impact on the future capabilities of NATO ground forces. It provides an estimate of when these underpinning technologies are likely to be mature enough to be incorporated in military systems as well as suggesting what their particular application may be. As a repository of current knowledge within the NATO countries, the primary purpose of this annex is to inform the reader; however it is also intended to stimulate debate -- predictions are always contentious and no document of finite size could ever identify all the contributing technologies that are ultimately likely to be relevant.

Over the past decade commercial competition has increased the investment in key technologies supporting applications for space, traffic and navigation, medical, biological, material, information technology, communications, new sources of energy, micro-technology, simulation and automation. We are now in a position where defence research actively seeks to exploit this civil research and combine it with the more specific military research to provide future military capability. Although exploiting civilian technologies must reduce overall costs for future equipment, a very significant research effort is required, and therefore cost, to integrate technologies into affordable concepts to meet future military requirements. Successful integration of technologies is the key to realising their potential military benefit, whether it is of civilian or military origin.

Finally, it must be remembered that research provides an opportunity as well as a threat. The time-to-market for innovations in the civil sector is an order of magnitude faster than for defence applications; therefore, unless procurement processes are streamlined, future adversaries could easily have a technological advantage over NATO in some important niche areas, for example, communications. Future adversaries may also be able to purchase advanced weapons from other sources specifically to attack our vulnerabilities.

The following pages provide an overview of the underpinning technologies that are most likely to make a significant impact on the future capabilities of NATO ground forces.

Index to Annex 4

4.1 TECHNOLOGY AREA: NOVEL ELECTRIC TECHNOLOGIES

Introduction

Apart from other types of energy electrical energy will reach an increasing significance for almost every item of military equipment on the future battlefield. Even weapon systems such as *small* to large calibre guns which in the past have only used energetic materials as their source of energy will in the future have a need for electric energy, be it to drive functional parts or be it for fire control purposes up to propelling projectiles in gun-tubes or other launching means. A specific significance will be in automatic and robot systems the operation of which as well as the functioning of sensors and data processing is not conceivable without electric energy. Vehicle drives up to the main battle tank are already in the discussion to be changed to electric energy offering advantages relative to weight distribution space savings and the overall drive technology and even the future infantry soldier cannot do without electric energy since thought is given already now to a wide use of sensors up to air conditioning of the combat suit and supporting means to move in the terrain and the whole area of reconnaissance, command and control, information processing, communication, etc. on the battlefield cannot be realised without an ever growing requirement for the availability of electric energy.

Also in future the provision of electric energy on the battlefield will primarily have to come from the combustion of chemical energy sources, mostly fossil fuels, since electricity cannot be made available by stationary plants. The generator must be mobile as the consumer. Smaller needs of energy do not seem to be the problem. The problem lies within the availability of large amounts of electric power as needed for electric driven vehicles, for high power electric weapons such as Electro-Thermal-Chemical (ETC) or even Electro-Magnetic (EM) guns or other Directed Energy Weapons (DEW) such as High-Power-Lasers to be foreseen in the future, when employed from mobile system platforms. Today's technology available to provide for such large amounts of electric power on the battlefield is far too voluminous and heavy to be carried on mobile system platforms. Not only the generation but foremost the storage of electric energy to have it available at all times in all places will afford great steps forward before electric driven armoured vehicles and electric weapons may become feasible.

To increase the use of electric energy on the battlefield to the foreseeable extent outlined above intensive investments for development of the following technologies will be imperative

- Battlefield Electric Power Generation
- Electric Energy Storage and Distribution
- Electric Drives and Propulsion
- Electric Armaments and
- Superconductivity

where superconductivity is to serve mostly to reduce the overall need for electric power consumption by the reduction of losses within a system as well as it can serve storage purposes for electric energy provided that the basic requirements related to this technology will be solved.

In the following the state of the art in development of the above mentioned technologies and their implications on the battlefield of the year 2020 will be discussed.

4.1.1 **Battlefield Power Generation**

Description

Battlefield power generation, also in future, mostly will have to rely on the combustion of fossil fuels. Small nuclear, solar energy or other conceivable energy plants for reasons of safety and physical constraints can, as a rule, not serve the purposes of land battlefield applications as a whole.

For mobile continuous-power generation, the key to substantial weight reduction is to increase the generating and distribution frequency from the current standard of 60 Hz to 400 Hz or higher.

Internal combustion turboshaft (gas turbine) engines, which are already in use for mobile electric power, offer more potential for the future than the alternatives (internal or external combustion piston engines and fuel cells) for mobile continuous power generation. A turbine running at 24,000 rpm can drive a 400-Hz alternator directly, without the heavy gearing now needed to drive 60-Hz alternators. Continued support for the Integrated High Performance Turbine Engine Technology (IHPTET) program (for aircraft propulsion) can realise the potential of this technology, when coupled with an aggressive effort to advance the technology for high frequency, lightweight alternators, power conditioners, and distribution systems. This effort could raise the power-to-weight ratio for mobile electric power units from the range of 0.05 kWe/kg (kilowatts of electricity per kilogram) for current 60-Hz gas turbine units to more than 3 kWe/kg.

In power generation and distribution, the use of high voltages can also decrease weight; the conductor weight required for a given wattage decreases as the square of the voltage. Improvements in high-voltage semiconductor devices would allow an increase from the current limit of about 1 kV to levels at which a power-to weight ratio of 5 kWe/kg would be possible for a mobile electric unit.

Directed energy devices and other electrically energised high-power systems will require generators for pulsed and short-duration power whose average power for the duration of output ranges to hundreds of megawatts. In both the mass and bulk (volume), generators in this class are half-prime power unit and half power-conditioning unit. For the prime power unit, the technologies with the most promise for the Army are gas turbine engines (for energy production) and flywheels (for energy storage). For power conditioning, new, molecularly tailored solid state devices and improved methods of heat removal should make possible an order-of-magnitude reduction in weight.

For power conditioning in pulsed or short-term generators, the development of high-temperature, high-power electronics is crucial. In particular, continued evolution along present lines must be pursued for capacitors, inverters, switches, and transformers. For each of these components, the combination of high voltage, high frequency, and high power requires technology that is beyond the current state of the art but not out of reach.

Availability

Estimate of technology maturity for full-scale system engineering development: 2010

Impact on military ground force capability:

- Battle zone electric power will permit efficient electric drive vehicles, provide power reserves for laser weapons / high power microwave weapons, and allow long term mission profiles for robotics, drones and Unmanned Aerial Vehicles (UAVs).
- This technology will reduce burdens associated with energy efficiencies of new power generation, storage and switching capabilities. It is a key enabling technology for electric guns and vehicle propulsion technology.
- The development of lightweight batteries/energy storage mechanisms will allow practical power sources for soldier systems (computers, data radios, night vision equipment, etc.).
- Ground Forces in all areas of application will gain largely from the availability of systems based on electric energy.
- Without a guaranteed provision of electric power generation at all times, however, it will be premature to largely invest in the procurement of ground force systems depending on electric energy. Therefore the electric power generation technologies, as well as the storage and distribution, are most essential

4.1.2 ***Energy Storage***

Description:

Batteries, Electrochemical Capacitors & Fuel Cells: The lithium/sulphur dioxide battery and other non-rechargeable and rechargeable batteries are the current infantryman's power source. These can produce instant power in all weather under considerable shock and vibration. Improvements are needed in power density, energy density, and affordability. High power densities are needed for burst/satellite communications, and small electric equipment cooling (microclimate cooling) laser devices. Extremely rapid and reversible rechargeability of new batteries will be required to allow use on the battlefield, with primary power sources which are less versatile but can supply extremely high energy densities for missions of long duration (e.g. microturbines, fuel cells and in addition thermophotovoltaic generators and solar cell panels as applicable. These performance needs translate into the need for more reversible and energetic electrode materials and for new solid electrolytes which will provide ionic conduction by motion of respective ions only. No concept yet exists for batteries that can provide power densities of both charge and discharge in the range of several kilowatts/ kilogram with cycle life of tens to hundreds of thousands of cycles.

Although the power density of batteries can be improved by more than an order of magnitude, energy density per discharge cycle is susceptible to more modest improvement.

For lengthier missions, where improved energy density is essential, fuel cell systems (often to be used with a rechargeable battery) appear to be a good choice for the future. New protonically-conducting electrolytes and electrocatalysts which will permit the utilisation of safe liquid fuels will be required in order to achieve miniature fuel cell systems which can operate under most battlefield conditions.

Research requirements include highly stable ultra-high surface area electrode materials and nonaqueous electrolytes with a very wide window of voltages in which there is no degradation due to electrochemical oxidation or reduction.

Availability:

Estimate of technology maturity for full-scale system engineering development: Technologies for storage of electric energy 2010 - 2020

Impact on military ground force capability:

Ground Forces in all areas of application will gain largely from the availability of systems based on electric energy. Beside the generation of the electric energy the storage must likewise be guaranteed especially in systems not directly connected to power generation facilities. This even more where a high power density is required in a very short time as in directed energy weapons and in electric guns.

4.1.3 ***Electric Propulsion Technology***

Description:

Electric drives are one of the most promising propulsion and power distribution systems for ground vehicles in 2020. Either an all-electric or hybrid-electric system will provide dramatic improvements in all areas of electric-drive technology. The advantages relative to other power transmission approaches include:

- improved weight distribution, since components are modular;
- individually driven wheels or track drive sprockets, eliminating complex transmission/ differential drive trains;
- a common power distribution system for vehicle drive, electrically powered weapon systems (such as an electrically energised hypervelocity gun), and power storage.

Power storage is essential for electric propulsion technologies and great advances in power storage and distribution are required. Internal combustion turboshaft (gas turbine) engines, which are already in use to run electrical power generators for mobile electric power, offer great potential for the future for mobile continuous power generation but improved energy storage is essential. Two such systems that offer particular promise are advanced batteries (perhaps a five-fold improvement over lead-acid batteries) and flywheels (four-fold improvement or more) for energy storage. The anticipated advances in flywheel technology will come primarily from new composite materials with high ratios of tensile strength to weight. These materials will increase energy density by an

order of magnitude over flywheels made with high-strength steels. The cost of fabrication for composite flywheels should also decline dramatically over the next 30 years.

Availability:
Estimate of technology maturity for full-scale system engineering development:

- Electrically driven vehicles 2000

Impact on military ground force capability:

- Electrical power transmission up to 1.5MW is realisable within short to medium term for all tracked or wheeled vehicles. The advantages of electric power transmission are: lower volume, omission of various mechanical and hydraulic components, a reduced basic performance at optimum speed as well as lower gross weight. Use of electric drive/propulsion will allow more efficient mobility characteristics and more efficient and survivable vehicle design. For example, a vehicle with independent drive components would not need torsion bars and could be designed with a lower profile while maintaining the same ground clearance.
- Electric drive/propulsion will provide significant savings in fuel efficiencies and vehicle weight thereby decreasing the logistics-transportation burden for deployment and combat operations. This will make a force more independent and flexible in operations on a non-linear battlefield.

4.1.4 ***Electric Armaments Technology***

Description:
Electro-Thermal-Chemical (ETC) guns are advanced cannon systems which use injected electrical energy to supplement conventional propellant to achieve perhaps 30 % to 40 % higher muzzle energies than are possible with conventional tank or artillery cannon. The injected electrical energy initiates a plasma which is used to rapidly ignite and control the conventional propellant throughout the burning process allowing for optimum energy generation for that cannon.

The amount of electricity and timing of the process may allow tuneable performance of the ETC cannon (a smart gun). Different electricity/propellant combinations may be selectable for discrete ranges for indirect fire.

Another possibility to enhance and simplify performance is the use of unitary charge technology that provides for exactly measured packaged charges that are easy to handle and load. The use of a number of discrete charges simplifies the loading process and ammunition logistics. The use of ETC and unitary charge technology will provide a system that will be much easier to automate and provide opportunities for decreased manning and associated efficiencies.

Electromagnetic (EM) guns use electrical energy alone to launch projectiles from rail or coil guns. The electrical energy is used to create a powerful

electromagnetic field that is used to launch a projectile at extremely high velocities (hypervelocity). The projectile is accelerated by electromagnetic energy rather than by gas pressure from burning propellant. Since no propellant charges are required, the technology reduces vulnerability.

Since ETC guns, but even the more EM guns, require great amounts of electric energy between 5 to 60 Megajoules to be provided by onboard generators and stored accordingly it largely depends on the availability of these basic technologies before such weapons may be considered for use in tank and anti-airtarget guns including artillery.

Availability:
Estimate of technology maturity for full-scale system engineering development:

- Electrothermal-Chemical Gun 2010
- Electromagnetic Gun (depending on energy storage availability) 2020

Impact on military ground force capability:

- The ETC gun will provide increased range and precision control of artillery fires towards pinpoint targets with minimum collateral damage. The electrical power generated and stored for the ETC cannon is also available for vehicle propulsion (electric drive) or other power requirements. This technology will enhance the performance of artillery weapons but could also be applied to direct fire weapons.
- EM gun technology will provide for the defeat of next generation armours by hypervelocity projectiles enhancing less vulnerability. It will also provide precise velocity control for defeating recognised targets (dial a charge). As with ETC, EM gun electric power will be available for vehicle electric propulsion and/or for novel electric armour provided the storage of the required large amount of electric energy will become available for mobile systems.

4.1.5 ***Superconductivity***

Description:
In all fields of application of electric energy the problem of losses exist to a large extend. Superconductivity is a means to reduce the electric resistance substantially. As an inductive storage device for electric energy superconducting coils are in discussion offering energy densities of up to 100 MJ per ton under the condition that high (ambient) temperature superconductors can be developed in time.

Until a few years ago the use of superconductivity required complicated and expensive liquid helium cooling. The application of superconductivity was therefore confined to some fields such as superconducting coils used in resonance tomographs for medical diagnostics and by no means for mobile military platforms.

The discovery of High Temperature Superconductivity (HTSc) in 1987 allowed the use of new materials (e.g. $YBa_2Cu_3O_7$) with considerably higher transition temperature (approx. 77 K) requiring only nitrogen cooling, which is less complicated and expensive.

HTSc can be used in both power engineering technology (i.e. transformers, cables, current limiters, energy storage devices) and microelectronics (i.e. microwave satellite technology, telecommunications). The main advantage of HTSc over conventional components is a considerable miniaturisation combined with a simultaneous increase in performance.

Availability:
Estimate of technology maturity for full-scale system engineering development:

- Josephson elements 2005
- Use of superconducting coils with environmental transition temperature 2015+

Impact on military ground force capability:

- In the field of ammunition propulsion, superconducting coils enable the power supply of an electromagnetic or electrothermal chemical gun to store loss-free electric power and supply electric current in picoseconds (10^{-12} s) to a plasma to be generated by it. The electrothermal-chemical gun permits muzzle velocities of far more than 2000 m/s to be achieved. Due to the high velocity (and flatter trajectory) of the fired projectile, a tank gun may fight with a greatly simplified fire control system and a higher probability of kill, at all required ranges. Applying this technology to artillery weapons will greatly increase range.
- Using the Josephson effect it is possible to build magnetometers to detect very small differences in a magnetic field (e.g. armoured vehicles, mines etc.)

4.2 TECHNOLOGY AREA – SENSOR, DIRECTED ENERGY AND COMMUNICATIONS

4.2.1 LASER-Directed Energy

Introduction:
There are numerous military current and future applications of lasers. For example: range finders, target designators, beam riders, radar, communications, and weapons. There are also many different types of lasers currently in use and more will emerge from R & D programs. All of the various types of lasers have different properties and hence may be more or less suitable for a specific application. For a laser weapon it is the target in question and operating environment which determine the required laser properties, for example: beam energy, wavelength, pulsed or continuous mode, peak power, etc. and rain, fog, obscurants, distance to target, etc. The sensitivity of the target and the range at

which it must be engaged are two of the main factors in determining the selection of the type of laser to be used. The definition of what constitutes a 'high power' or 'high energy' laser is rather ambiguous. Some experts use numerical values for power and energy while others define a laser that can physically damage a target to be high energy. The applications for high power/energy lasers as a weapon can be divided into three broad areas in increasing order or power/energy requirements:

- dazzle/deception of sensors
- damage to sensors/optics and
- structural damage.

The main damage mechanism in a target caused by a laser is thermal. At high energies the mechanism is thermomechanical in that the rapid input of heat to the target material can induce high-pressure waves or shock waves in the target material resulting in failure. Current and future sensor/optic systems will operate at visible and infrared wavelengths. Practical limitations, for example transmission through the atmosphere, define the following useful wavebands: visible (0.4 - 0.7 μm), near infrared (0.7-1.4 μm), mid infrared (1.5-5.5 μm) and far infrared (8-14 μm). Sensor/optical systems are most easily defeated at wavelengths in-band. However, a priori knowledge of the in-band wavelength for all potential targets is unlikely as well as these systems will be protected with laser countermeasures such as filters. Therefore the entire useful visible and infrared (IR) band must be employed either by multiple lasers, tuneable optical devices or tuneable lasers. There are a number of basic types of lasers as described below. Given the many types of materials and their variants that can be used in these types of lasers, the number of wavelengths that can be produced is almost infinite.

4.2.1.1 Laser Types

Solid State Lasers

Solid state lasers use a solid rod composed of a crystal or glass which is doped with atoms that absorb. The pump energy causes the population inversion of the energy levels and stimulates the laser action. The characteristics of the different solid state lasers depend both on the active and substrate materials. There are many suitable active materials such as the elements of chromium, neodymium, erbium, holmium, cerium, cobalt and titanium. The substrate materials can be either a glass or artificial crystal for example yttrium-aluminium garnet (YAG). Neodymium (Nd) is the most common material used in solid state lasers. Two of the most common lasers are Nd:YAG and Nd:glass. A flash lamp or another laser can pump these types of lasers, for example a diode laser. Pumping by a laser diode array has the advantages of higher efficiency by a factor of 10X as well as a lower cooling requirement. The wavelength of a neodymium laser (1.06 μm) can be varied considerably by using non-linear optical parametric oscillators (OPOs). Similarly, Q switching can modify the pulse duration. Some types of solid state lasers are tuneable over a wide wavelength band. For example, the alexandrite laser which uses a chromium-doped chrysoberyl crystal, designated as $Cr^{3+}:BeAl_2O_4$ has a wavelength band of 0.7 - 0.82 μm and the titanium-sapphire laser has the broadest bandwidth (0.66 - 1.18 μm) of any laser.

Semiconductor (Diode) Lasers

Semiconductor lasers are small, efficient laser devices with typical dimensions of less than a millimetre. They operate typically in the wavelength range of 0.5 - 1.55 μm, depending on the materials used for the laser medium. The laser consists of two-doped semiconductor materials directly adjacent to each other which form a diode. When an electric current flows through the junction between the two materials, the electrons are raised to an excited state that will emit light. This simple type of single junction laser (homojunction laser) generates significant heat and is not a practical configuration. Heterojunction lasers consist of several layers of various materials: semiconductor materials, both doped and undoped; insulating layers, usually in the form of oxides; and metallic layers for conduction of current. A single layer in the centre of these layers is the active layer where the gain is produced. The most common materials used are gallium arsenide / aluminium gallium arsenide (GaAs / AlGaAs) or indium gallium arsenide phosphide / indium phosphide (InGaAsP / InP). These are III-V semiconductor alloys. Recently, lasers have been produced using gallium nitride (GaN). The II-VI compounds such as zinc selenium (ZnSe) have been demonstrated at the research level. Semiconductor lasers can be operated in the continuous-wave or pulsed mode.

If the active layer thickness of the semiconductor laser is reduced to the order of 10 nm then the valence and conduction bands are changed from continuous to discrete. The net effects of this laser device are to decrease the threshold current, and to minimise the volume of material that generates heat, since most of the heating occurs within the active layer. This type of laser is called a "quantum-well laser". By using layer materials with different lattice dimensions than the substrate and thereby disrupting the regular alignment of the atoms it is possible to change the wavelength of the laser. This type of layer is referred to as a strained quantum well.

By arranging rows and layers of semiconductor heterojunction lasers in various configurations and arranging for simultaneous operation of the lasers, the result is a coherent output from a "diode-laser array". The technology issues that need to be resolved to take these devices to high power are: removal of waste heat, phase locking of large numbers of diodes, and the coherent combining of modules into high power arrays.

Gas Lasers

Gas lasers use a pure gas or a mixture of gases which are excited to produce a laser beam. They use electron collision pumping, with an electric current passing through the gas. However, some gas lasers use optical pumping with flash lamps or another laser, and others use chemical reactions. A wide range of different gases and mixtures of gases are suitable for laser operation. It is only necessary that the gas have energy levels that are capable of achieving population inversion.

One of the first high-energy lasers was the carbon dioxide CO_2 gas laser. It operates in the mid infrared range at 10.6 μm or 9.4 μm wavelengths. Both pulsed and continuous-wave occurs in several types of gas discharge configurations. There are a number of different types of laser structures used for

the CO_2 laser including: longitudinally excited, waveguide, transversely excited and gas dynamic. The gas dynamic configuration of CO_2 laser produces the highest power of the various types and would be most suitable as a military weapon. This laser functions by burning a hydrocarbon fuel in oxygen or nitrous oxide, resulting in a hot gas which flows through nozzles, expands quickly, and achieves the population inversion required to amplify the energy. The gas then flows at supersonic speed through an optical resonator, where stimulated emission occurs, and the energy is emitted as a laser beam.

Chemical lasers are similar to the CO_2 laser in that they use a combustion process. The pumping energy is obtained from a chemical reaction. The two most well known chemical lasers are based on hydrogen fluoride (HF) and deuterium fluoride (DF). The HF laser emits in the wavelength range of 2.6 - 3.3 µm, which is a region of high absorption in the atmosphere. The DF laser emits in the wavelength range of 3.5 - 4.2 µm, which is a region low atmospheric absorption. Other chemical lasers of interest are the carbon monoxide (CO) and iodine:oxygen (I_2:O_2) lasers.

Dye Lasers

Dye lasers use a liquid gain medium consisting of strongly absorbing and emitting organic dyes dissolved in a solvent. There are over 200 laser dyes that when used sequentially can produce tuneable laser output over wavelengths ranging from 0.32 µm to 1.2 µm. There are 3 main types of dye lasers: pulsed, continuous-wave (CW) and mode-locked. Pulsed and CW dye lasers are pumped by other lasers operating in the same mode. The mode-locked laser is also pumped by another laser and uses a multiple mirror system to produce extremely short pulses. The main advantage of dye lasers is that the wavelengths cover the entire visible spectrum.

Free Electron Lasers

Free electron lasers (FEL) differ from conventional lasers that are based upon creating a population inversion between energy levels of discrete bound states of materials. In a FEL electrons oscillate in a vacuum, void of any gain material other than the electrons themselves. A high energy electron beam is used to accelerate electrons through a magnetic field consisting of an array of magnets in which every other one has reversed polarity. This field causes the electrons to change directions sharply, which results in emission of energy. This energy is formed into a laser beam in the conventional way by the use of mirrors in a resonator cavity. The main advantages of a FEL are high efficiency, tuneability over a broad part of the spectrum, and high power.

Limitations of use:

In the past the use of lasers on the military battlefield was limited to range finding target designation and communication means. In the meantime lasers may be considered as a secondary weapon to irritate or defeat sensors or to defeat non-armoured aerial targets or guided missiles. In addition due to physical restraints caused by weather conditions lasers weapons are somewhat limited as well as the international laser convention ratified not long ago prohibits the use of lasers against the human eye.

Technology Areas for Advancement

The capabilities required for high power/energy lasers in weapons applications are functions of the target and the intended mechanism of defeat. For example sensors can be defeated by fluences of 10^{-4} to 1 J/cm^2. To achieve a structural kill on a target that requires penetration of a layer of material to thermally damage some critical component requires fluences of 2 to 40 kJ/cm^2. It is expected that for land operations in the year 2020 that chemical lasers mounted on a mobile platform could provide the required fluences for a structural kill. However, free electron lasers would be restricted to a fixed site. For the defeat of sensors either by dazzle/deception or structural damage, laser diode arrays will be used for both pumping of solid state lasers and as coherent laser sources.

4.2.1.2 High-Power Laser Technology

Once only used in complicated laboratory devices, laser technology is now applied reliably with multiple applications in the field of natural sciences, medicine and military technology. This trend is increasing. The present development objectives are: miniaturisation, more stable compact designs, better performance, better beam quality and the establishment of new wavelengths and better handling.

Important advances have occurred in solid state laser technology since the mid-1980s. Their all-solid state design provides advantages of high reliability and low maintenance. Mass production techniques for solid state materials and for laser array pumps promise low cost as well. At present, designs with longitudinal pumping give the highest efficiencies, but transverse pumping of solid state laser slabs by two-dimensional diode laser arrays is better suited for higher power levels, albeit at modest efficiencies.

For example, the projected capability of a neodymium laser demonstrator is 300-W average power, about 10 percent efficiency, and a lifetime of greater than 10^9 shots. Various wavelength conversion techniques will enable this demonstrator or similar devices to be wavelength-selectable from the visible to the mid-infrared at greater than 100 W. This average power level exceeds the minimum required for many space-based and tactical applications.

This solid state laser technology will provide relatively eye-safe laser rangefinders and target designators that are more reliable than those now fielded. In addition, however, it will lead to new applications, such as laser radars, active optical countermeasures (anti-sensor lasers), and high bandwidth laser communication from satellites to theatre and battlefield commanders.

A related area is diode laser and laser array technology. While individual diode lasers are limited in power, coherent arrays will yield 10 W or more of output at greater then 40 percent efficiency. Scaling to over 100 W average power may be feasible, with power densities exceeding 100 W per square centimetre. Varying the semiconductor material will enable these arrays to operate in the visible region, at (relatively) eye-safe wavelengths above 1.4 microns, and even in the 2- to 5- micron range that is used for laser-activated proximity fusing.

For military purposes Lasers will become feasible for the following applications:

- In the past low energy lasers have been used mainly for measuring and communication purposes whereas in the future the application of high energy lasers for the destruction of sensors or vulnerable structures like helicopter cockpits or the protection against those types of lasers will be a central issue.
- Rangefinders and target designators will continue to be improved providing an increased capability to maximise the use of smart weapons.
- Optical countermeasures, laser radars (LADAR), high bandwidth laser communications and Combat Identification Friend or Foe (CIFF) are new laser applications that will play an increasingly important role in sensor dominance and information warfare architectures.
- FEL lasers can be used for defence against missiles in their boost phase providing instantaneous missile intercept and destruction.

Availability:
Whereas High Power Semiconductor Lasers and Laser Directed Energy Weapons in an anti-sensor application will become available by approx. 2005, FEL-Lasers Weapons, i.e. against missiles in boost phase, will hardly be feasible before 2020. As for high power electric weapons and electric vehicle drives the main technology problems to be solved is the availability of high power electricity at all times and in all places (mobility).

Basic underpinning technologies for High Power Lasers can be roughly divided into two groups:

- new materials such as semiconducting polymers (2.1.3), optical coatings (2.1.4) and non-linear optical materials (2.1.5), and
- new devices/processes such as quantum dots (2.1.6), adaptive optics (2.1.7 and 2.1.8) and optical parametric oscillators (2.1.9).

4.2.1.3 Semiconducting Polymers

Description:
A semiconducting polymer as a laser material is a very new technology. Only recently, optically pumped luminescence and stimulated emission, gain and lasing has been demonstrated in more than a dozen different semiconducting polymers with emission spectra that span the entire visible spectrum. These materials combine the optical and electronic properties of semiconductors with the processing advantages and mechanical properties of polymers.

The side chains on semiconducting polymers provide two functions. First, they make the polymers soluble in common organic solvent, thereby enabling processing from solution into uniform, large-area, optical-quality thin films. Second, they tune the energy gap of the polymer and hence the emission colour.

Semiconducting polymers offer important advantages as a laser material. First, due to the relatively large spectral shift between absorption and emission, the intrinsic loss is small. Second, because the absorption and emission are spectrally separated, optical pumping the excited state does not simultaneously stimulate emission. Third, these polymers exhibit little concentration quenching and can have photoluminescence efficiencies as high as 70%. This is a considerable advantage over laser dyes that must be diluted to optimal concentrations. Finally, these are highly absorptive materials and absorb 90% of the light at the wavelength of maximum absorption.

Relationship with High Power Laser Technology Area:

The unique features that make semiconducting polymers attractive as laser materials have wide applicability. For example, recent progress in gallium nitride (GaN) technology has enabled the development of blue light emitting diodes (LEDs) and blue laser diodes using indium gallium arsenide (InGaN) quantum-well structures. LEDs have been fabricated that emit light of any colour by using a polymer coated InGaN LED as the short wavelength pump source for the polymer film. There is the potential of using this type of polymer/InGaN hybrid to produce a diode laser in the near future. By extension a semiconducting polymer diode laser array will be the next step.

Availability:

Estimate of technology maturity for full-scale system engineering development:
2010

Impact on military ground force capability:

Semiconducting polymer diode laser arrays will result in systems that are more compact and efficient. They could potentially be used as the pump sources for other lasers and coherently combined to form a high power array.

4.2.1.4 Optical Coatings

Description:

The high energy densities in a laser environment present special challenges for coated surfaces. The coating is usually the weakest link in a laser optical system since the coatings exhibit the lowest damage thresholds. The laser-induced damage threshold is different for continuous-wave and pulsed lasers. The damage mechanisms are not completely understood yet, but generally, continuous irradiation or pulses of microsecond duration appear to cause damage by heating-induced stress effects. Pulsed energy in the nanosecond range interacts with surface defects on the substrate which results in a plasma which disrupts the coating layer. Improved surface preparation and film deposition processes can increase damage thresholds. There are a variety of materials available for optical coatings for example fluoride, oxide and zinc compounds. Threshold values for specific materials are dependent on wavelength, pulse duration, repetition rate, coating configuration and deposition conditions.

Relationship with High Power Laser Technology Area:

Current available optical coatings cover a narrow wavelength for a particular material and deposition process. Since tuneable optical devices or tuneable lasers will be required to defeat potential targets covering a wide wavelength band, new materials and deposition processes will have to be developed particularly for high energy operation over this band.

Availability:
Estimate of technology maturity for full-scale system engineering development:
2010

Impact on military ground force capability:
Advances in optical coatings will allow higher laser energy operation over a wider wavelength band.

4.2.1.5 Non-Linear Optical Materials

Description:

When electromagnetic waves propagate through a medium they produce polarisations in the medium which oscillate at all possible sum and difference frequencies that can be generated from the incoming waves. These polarisations result in electromagnetic waves with the new frequencies. This phenomena forms the basis for various frequency mixing processes such as frequency doubling, tripling, four-wave mixing and optical parametric oscillators (OPOs). There is a wide range of non-linear materials suitable for such processes. In addition to having a high non-linear coefficient, these materials must be transparent at both the laser frequency and the newly generated frequency. They must also be resistant to optical damage, have high mechanical hardness, exhibit good thermal and chemical stability, be capable of being grown in useful sizes, have the appropriate phase matching properties, and free from scattering and lensing effects. Examples of non-linear materials include: lithium triborate, potassium niobate, lithium niobate, potassium dihydrogen phosphate, zinc germanium phosphate, and silver gallium selenide. Continued research on crystal fabrication techniques and the development of new materials will lead to the capability to handle higher power laser beams.

Relationship with High Power Laser Technology Area:
Tuneable optical devices or tuneable lasers will be required to defeat potential targets covering a wide wavelength band. Tuneable optical devices will involve frequency conversion by techniques such as second harmonic generation or using an optical parametric oscillator. Both of these require the use of non-linear optical materials.

Availability:
Estimate of technology maturity for full-scale system engineering development:
2010

Impact on military ground force capability:

Advances in non-linear materials technology will provide more efficient laser components

4.2.1.6 Quantum Dots

Description:

Quantum dots are nanostructures that form automatically when growing semiconductors with large lattice mismatch. After growth of approximately 1.5 layers of material on the substrate, the growth changes from a layer-by-layer mode, which is normally used to grow common heterostructures, to a mode where small uniform islands 'dots' appear. A quantum dot laser diode can be grown by molecular beam epitaxy or by metallo-organic chemical vapour deposition. Varying the growth temperature and the amount of material deposited can control the size and density of dots. The emission wavelength is controlled by the size of the dot as well as the alloy composition. It has been demonstrated that quantum dots have increased threshold performance in comparison to quantum well lasers.

Relationship with High Power Laser Technology Area:

Quantum dots can be produced with a mature epitaxy growth process, without additional processing, and their ability to emit at a range of wavelengths, would allow them to be integrated into practical devices after the fundamental issues have been resolved and the device optimised. It is expected that as the quantum dot laser technology matures it will replace the semiconductor quantum well lasers.

Availability:

Estimate of technology maturity for full-scale system engineering development:
2010

Impact on military ground force capability:

With the increased performance of quantum dot technology it is expected that a decrease in size of semiconductor lasers will occur for a fixed level of laser energy/power output.

This technology would also be applicable to high-density optical memories in computers.

4.2.1.7 Optical Parametric Oscillators (OPOs)

Description:

An optical parametric oscillator (OPO) is a device consisting of an optical harmonic crystal within a two-mirror resonator. An input laser beam at the pump frequency interacts with the crystal resulting in two output frequencies (signal and idler). The signal and idler wave will be amplified provided the frequencies are phased matched. The signal and idler frequencies are adjusted by phase matching to maximise the gain so that these frequencies will achieve the lowest

threshold and be selectively amplified. Therefore the output of an OPO is wavelength tuneable. Tuning can be achieved by angle or temperature control of the phase matching i.e. adjusting the angle of the crystal relative to the input beam or the temperature of the crystal. Another technique of phase matching non-linear optical interactions is called Quasi Phase Matching (QPM). In QPM the relative phase is corrected at regular intervals using a structural periodicity built into the non-linear medium. One technique to invert the phase is to change the sign of the non-linear coefficient. This can be done, for example, by forming a stack of thin wafers of the non-linear crystal and rotating alternate wafers by 180°. A relatively new development is to use a ferroelectric crystal to form regions of periodically reversed spontaneous polarisation. An example of this type of material is periodically poled lithium niobate. With a near infrared input this material can be used to generate wavelengths ranging from 1.3 µm to the transparency limit of the material near 4.5 µm.

Relationship with High Power Laser Technology Area:

Optical parametric oscillators used with a laser will provide the capability to defeat potential targets covering a wide wavelength band. New materials will provide the capability to scale current devices to higher energy levels and an extended range of wavelengths.

Availability:

Estimate of technology maturity for full-scale system engineering development: 2010

Impact on military ground force capability:

Optical parametric oscillators will provide the basis for a simple, efficient and deployable means for converting laser output to different wavelengths. They will be particularly useful for defeating fixed-line protective filters used in some types of sensor systems.

4.2.1.8 Adaptive Optics (Optical Phase Conjugation)

Description:

Optical phase conjugation uses a non-linear mixing process to generate the perfect counter-propagating wave, both in direction and phase, of an incident wave. The consequence of this is that if a wave travels through a medium that distorts its optical phase fronts, such as an aberrated optical system or along an atmospheric path, then after a reflection at a phase conjugate mirror the wave will retrace its path and the phase distortions produced on its outward path to the phase conjugate mirror will be exactly unfolded on the return path, so the wave returns to its starting point undistorted. In the construction of laser systems there are always severe limitations. A laser gain medium may have static or dynamic refractive index non-uniformities; as an amplifier, there are size or length limitations associated with amplified spontaneous emission. There are also repetition rate limitations associated with heating, thermal distortions, and thermally induced birefringence, and there are often other limitations. Optical

phase conjugation provides a new technique that overcomes some of these significant performance limitations. There are two main types of optical phase conjugation techniques, stimulated Brillouin scattering (SBS) and four-wave mixing (FWM). In general, stimulated Brillouin scattering applies to high-energy lasers and four-wave mixing to lower energy lasers. In the SBS technique, an intense optical beam is focused into a wave-guide containing materials that exhibit SBS. This technique uses an inelastic process where an intense laser beam is back-scattered as a result of sound waves, which are produced through an electrostrictive effect. The coupling of the two light waves (input and retro-reflected) with a sound wave results in phase conjugation. FWM uses a non-linear material with a third order susceptibility tensor (third harmonic generation). Since four frequencies are involved this process is called four-wave mixing.

Relationship with High Power Laser Technology Area:

Optical phase conjugation provides the capability to a given laser system at a higher repetition rate, or in a manner more tolerant of environmental issues such as jarring, shocks and rapid acceleration. Furthermore, phase conjugation devices may allow new architectures for scaling medium and high power laser multiple gain media (parallel channel) systems to greater performance levels by being able to treat a large assembly of laser gain media as if it were coherently providing a single phase output.

Availability:

Estimate of technology maturity for full-scale system engineering development: 2010

Impact on military ground force capability:

Automatic pointing and tracking laser systems are of significant military importance. Suppose it is desired to focus an intense laser beam on a moving target through the turbulent atmosphere. It is possible in principle to generate the phase conjugate of a weak signal that has travelled back from target to source location and then amplify this weak phase conjugate signal and project it back to a small focal spot on the target.

To evaluate the range and effectiveness of such a device, it is important to determine how faint a glint (off a target) a phase-conjugate controlled laser requires to deliver a significant amount of laser energy to that target. Researchers have conducted an investigation in which they have successfully phase conjugated approximately five photons while amplifying the signal by 10^{17}. This work has significant implications regarding the automatic negation of targets in a tactical laser engagement, to the establishment of secure optical communication links and to imaging applications.

For military applications size and weight are important considerations. Therefore, improvement of the effectiveness of a laser by using phase conjugation provides the capability of scaling up the power of the laser systems within these constraints.

4.2.1.9 Adaptive Optics (Deformable Mirrors)

Description:

An adaptive optics (AO) system comprises of a wavefront sensor to detect optical aberrations, electronic circuitry to compute a correction and a deformable mirror to apply the correction. Depending on the complexity of the system, the deformable mirror has tens or hundreds of actuators, each attached to a thin membrane that forms the mirror surface. The mirror can be either a continuous membrane or an arrangement of individual mirror segments. Continuous membrane mirrors have small diffraction effects due to the continuous nature of the mirror surface. However, the continuous membrane causes the actuators to be mechanically coupled, resulting in increased complexity in the mirror control algorithm. Segmented mirrors induce higher diffraction effects because of the presence of sharp edges in the mirror surface, but are generally not mechanically coupled, leading to simpler control algorithms. Small piezoelectric actuators are used to move the mirror segments or deform the continuous sheet.

Micro-electro-mechanical systems (MEMs) offer a new technique for producing AO. They can be fabricated using an existing micromachining process for semiconductor production. This process uses alternating layers of a structural material (polycrystalline silicon) and a sacrificial material (silicon dioxide). A base nitride layer insulates the surface micromachined layers from the underlying silicon wafer. These devices are at the research stage but have potential advantages over competing deformable mirror systems in performance, fabrication, and economy. MEM AO exhibit no hysteresis, making them easier to control. Since they are electrostatically driven and operate at low voltages they consume low power. They are light-weight and can be packaged closely in massively parallel arrays for high spatial resolution.

Relationship with High Power Laser Technology Area:

Adaptive optics are required in high energy laser systems to compensate for atmospheric turbulence, thermal blooming, and other disturbances to the laser beam. The wavefront sensor detects optical aberrations in the reflected laser beam, as a result of the disturbances, and provides this information as input to control the mirror surface shape and adjust the laser beam.

Availability:

Estimate of technology maturity for full-scale system engineering development:
2010

Impact on military ground force capability:

The use of a deformable mirror system will provide the basis for automatic tracking of a moving target. A laser would be focused on a spot on the target and the variable reflection characteristics of the target would be used to keep the laser on the same location.

4.2.2 ***RADIO FREQUENCY DIRECTED ENERGY***

Introduction:

RF DE promises to be a useful technology to attack and negate an enemy's electronic sensors, communications, and weapon guidance systems. It offers several advantages over conventional weapons, such as guns and missiles:

- Less pointing accuracy required, which means a higher probability of hit compared to conventional weapons (i.e., guns and missiles);
- Instantaneous time of flight for fast engagements
- Virtually unlimited "magazine" (as long as electrical power is available)
- A non-lethal means to attack an enemy when desirable.

RF DE technology can greatly improve the existing information/electronic warfare (I/EW) capabilities by allowing ground forces to perform in-band jamming that generally lasts as long as the RF is on target. Also, it causes out-of-band disruption that can last long after the RF is gone and possibly even cause permanent damage to the target's electronics. (This depends on the target's location relative to the RF DE source and the inherent hardness of the target). However, to determine the utility of RF DE technology, we must investigate the target vulnerability levels and develop RF sources and antenna technology that will provide the necessary power and modulation to cause target failure.

The application for RF DE will be to disrupt, degrade, deny, and/or destroy an enemy's capability for sensing a target, his communications, and weapon guidance systems in both offensive and defensive roles.

4.2.2.1 Radio Frequency Directed Energy Technologies

The radio frequency (RF) range of the electromagnetic spectrum covers the range from approximately 300 GHz to 3 kHz with corresponding wavelengths of 1 mm to 100 km. Within this range there are millimetre wave (MMW), high-power microwave (HPM) and electromagnetic pulse (EMP) regimes. EMP as generated by nuclear weapons or high explosive technology will not be included in this discussion since it does not apply to directed energy. RF weapons have the potential of being applied to any target which could be defeated by burning out electronic components, detonating electro-explosive devices or causing malfunction or upset of the device by producing false signals. Examples include: computers, mines, smart munitions, communication nodes, vehicle electronics, radar and infrared guided missiles, humans (non-lethal weapons), and global positioning systems (GPS).

The tolerance of a particular system to RF depends on many parameters. The RF energy can penetrate systems through the front door or back door. Front door coupling refers to energy that enters through the intended path for transmission and reception (antennas), whereas back door coupling refers to an inadvertent point of entry such as seams, connectors, windows, etc. The magnitude of the effects will depend on the degree of hardening of the system to RF. Also the RF beam characteristics (incident power density, incident energy

density or fluence, peak electric field strength, wavelength, and pulse length) are important parameters in the determination of system tolerance.

Microwave generation can be accomplished using different techniques and as a result a large variety of sources have been developed over the years. Each operates over a range of power levels and frequencies. One possible categorisation of HPM devices, that is based on the electron kinetic energy conversion to microwave energy or the wave-particle interaction is as follows:

- Plasma devices:vircator, orbitron, intense relativistic electron beam (IREB)
- Slow-wave devices:magnetron, backward-wave oscillator (BWO), travelling wave tube (TWT), relativistic klystron, magnetically insulated line oscillator (MILO)
- Fast-wave devices:gyrotron, cyclotron autoresonant maser (CARM), gyroklystron
- Parametric devices:Raman or Compton free electron laser (FEL)/ubitron

The microwave source is only one part of the system required to produce HPM for an actual application. A complete simple system includes: pulsed power source, electron beam source, microwave source, microwave components (eg. waveguide), and an antenna.

Technology Areas for Advancement

The capabilities required for radio frequency directed energy in weapons applications is a function of the type of target and the engagement range. For example with today's technology it would be possible to provide sufficient fluence to cause 'microwave' hearing in humans at a range of 10-20 km. By the year 2020 it may be possible to affect the nervous system. It is expected that for land operations in the year 2020 that RF weapons mounted on a mobile platform could provide the required fluences for defeat of a range of targets.

Underpinning technologies for the High Power Directed Energy Technology can be roughly divided into two groups:

- new materials such as high-temperature superconductors (2.2.2), photonic crystals (2.2.3) and ferroelectric materials (2.2.4), and
- new devices/processes such as high-power optically activated semiconductor switches (2.2.5), phased arrays (2.2.6) and high-power ultra-wideband microwaves (2.2.7).

4.2.2.2 High Temperature Superconductors (HTS)

Description:

Superconductivity is the ability of certain materials to transmit electric power with no loses. Metallic (low temperature) superconducting materials such as NbTi and Nb_3Sn have been used for years to produce the filaments for composite wires

with an ordinary metal jacket. The difficulty in using these composite wires is having to develop systems with cooling to liquid helium temperatures so that superconducting will occur. In 1986 a new class of materials, copper oxide perovskites, were shown to exhibit superconductivity at substantially higher temperatures than any previously known, hence the term high temperature superconductors. To date there are over 100 different materials which exhibit superconductivity with the highest temperature of approximately 155 degrees Kelvin.

Relationship with Radio Frequency Directed Energy Technology Area:

High temperature superconductors can be produced in bulk material or wire and tape forms suitable for the production of bulk annular magnets. Various HPM sources (e.g. magnetron, gyrotron, and intense relativistic electron beam) use magnets as part of the device. Superconducting coils (low temperature) have been used to produce the magnetic field for gyrotrons for many years. With the development of HTS and the capability to produce composite wires these low temperature coils could be replaced. Other types of HPM sources use tubes that use a linear electron beam, which requires an axial magnetic field over the length of the interaction region. This requirement could be filled by the use of melt-processed HTS bulk magnets.

Availability:

Estimate of technology maturity for full-scale system engineering development:
2010

Impact on military ground force capability:

HTS will provide two advantages:

- Elimination of continuous dissipation of energy in conventional coils;
- Provision of higher axial flux density than is available conveniently from permanent magnets or coils.

4.2.2.3 Photonic Crystals

Description:

Photonic crystals are two or three-dimensional periodic dielectric structures that exhibit ranges of frequencies (stopbands) where electromagnetic radiation is forbidden. If the stopbands are omnidirectional, the photonic crystal dispersion relation exhibits a forbidden region or bandgap. The width, depth and location of the stopband are determined by the shape size and location of the macroscopic atoms (scattering centers), as well as the longitudinal (along the direction of propagation) periodicity of the structure. Photonic crystals are a quasi-optical component that is fabricated by drilling holes in sheets of dielectric material such as a Ti-O_2 based compound and stacking three sheets such that they produce a face-centred-cubic lattice structure.

Relationship with Radio Frequency Directed Energy Technology Area:

Photonic crystals are a very new technology but have the potential to be used as components for HPM applications. Suggested applications emerging from the early research work include quasi-optical reflectors, filters, and beam forming components. For ultra-wideband excitation, photonic crystals of different periodicities could be stacked in tandem to obtain a photonic crystal capable of providing UWB reflectivity. Since photonic crystals are fabricated from low-loss high-dielectric-constant materials they have the potential for lower ohmic losses compared to metals. Furthermore, since they are a distributed reflector, the amount of energy reflected by each layer is significantly lower than a metal, which can alleviate surface breakdown problems. An example of a potential use is for the mirrors in an orotron resonator. In this HPM source an open resonator is formed from a pair of mirrors. The flat mirror has a grating surface. Opposite this mirror is a curved mirror with a hole. An electron beam is passed through between the mirrors and the microwave radiation is extracted through the hole.

Availability:

Estimate of technology maturity for full-scale system engineering development:
2010

Impact on military ground force capability:

By use of photonic crystals in HPM systems the ohmic loss and surface breakdown problems could be significantly reduced, therefore providing the potential for increased power for a fixed size of system.

4.2.2.4 Ferroelectric Materials

Description:

Ferroelectric materials exhibit a hysteresis effect whereby an applied magnetic field aligns the magnetic domains in the material. When the magnetic field is removed, there is a remnant magnetisation that leads to macroscopic magnetic properties of the material. Some ferroelectric materials such as barium titanate, lithium niobate, and the lanthanum-deficient lead titanates (such as PZT and PLZT) exhibit analogous behaviour, with the exception that the hysteresis is in electric polarization as a function of the applied electric field. When an electric field is applied to the material, a corresponding polarisation is produced. After removal of the field there is a remnant polarisation. This property can be exploited in ferroelectric cathodes. Electron emission is effected in these materials by using an applied electric field to rapidly change the material state from remnant to saturated, thereby changing the surface potential and causing electron emission. The ferroelectric materials lead-zirconium-titanate (PZT) and lead-lanthanum-zirconium-titanate (PLZT) have recently been found to have very high emission current densities on the order of 400 A/cm^2.

Relationship with Radio Frequency Directed Energy Technology Area:

HPM sources use the kinetic energy of electron in a beam or layer to produce the intense microwave fields. Electron beams and layers will continue to drive the highest power devices unless and until solid-state switching technology makes

devices such as frozen wave generators high-power contenders. The production of an intense electron beam or layer begins at the electron source. Electron emission can be produced by a number of phenomena as follows:

- Explosive emission - tens of kA/cm^2
- nonexplosive field emission - several hundred A/cm^2 to several kA/cm^2
- thermionic emission - several tens of A/cm^2 to 100 A/cm^2
- photoemission – 100to 200 A/cm^2

Each of the emission techniques have various advantages and disadvantages and the importance of the emission quality varies with the type of HPM source.

The use of the ferroelectric materials PZT and PLZT as cathode sources have several advantages compared to materials used for thermionic emission. They do not suffer easily from atmospheric contamination, operate at room temperature and are rep-rateable. Also the emission current densities are above those for thermionic emission (used in klystron source) and into the range of nonexplosive field emission.

Availability:
Estimate of technology maturity for full-scale system engineering development:
2010

Impact on military ground force capability:
These materials will allow the production of more compact and efficient HPM sources.

4.2.2.5 High-Power Optically Activated Semiconductor Switches (OPSS)

Description:
Optically Activated Semiconductor Switches (OPSS) or Photoconductive Semiconductor Switches basically consist of two electrical contacts separated by a normally semi-insulating or intrinsic semiconductor medium. The resistance of the switch is controlled by optical illumination between the contacts. Laser light is used to excite electrons from the valence band to the conduction band in the semiconductor material. Laser diode arrays are suitable for providing the optical source for the switch. The majority of photoconductive switches to date use either silicon (Si) or gallium arsenide (GaAs). Other materials such as iron:indium phosphide (Fe:InP), gallium phosphide (GaP), have also been used. Diamond and diamond-like materials have promise for this application due to voltage capability and superior thermal properties. Photoconductive semiconductor switches have the potential to deliver pulses with gigawatt peak powers at multimegahertz repetition rates, and subnanosecond opening and closing times have already been demonstrated.

Relationship with Radio Frequency Directed Energy Technology Area:
Photoconductive Semiconductor Switches have applications to high-voltage pulse generation and high-power ultra-wideband (UWB) microwave generation.

A process of pulse compression obtains the short, intense pulses of electricity needed to drive HPM loads. The energy taken from a low-voltage long-pulse system is compressed in time, increasing both voltage and current at the expense of pulse duration. Various pulsed power systems are used including Pulse Line Systems, Magnetic Stores, and Induction Accelerators. Each of these requires either rapid closing or opening switches. There is a wide variety of closing switches (e.g. spark gaps, thyratrons, thyristors, and exploding foil solid dielectrics) but only several types of opening switches (e.g. fuses, explosive, vacuum). Repetitive operation of switches puts a premium on switch recovery between pulses and on switch lifetime. Repetitive opening switches are particularly difficult. Photoconductive switches have great potential for this application in that they can be used in either the opening or closing mode and have better recovery time than any other fast pulse switch candidate.

An emerging technology in the RF area is the generation of microwaves by direct switching, which involves generation directly from an electrical source without the intermediate use of an electron beam. This high-power ultra-wideband (UWB) microwave generation is made possible by advances in photoconductive switches, ultrafast high-power lasers and ultra-wideband antennas.

Availability:
Estimate of technology maturity for full-scale system engineering development:
2010

Impact on military ground force capability:
Photoconductive Semiconductor Switches have three main impacts. First, the generation of HPM by direct switching will in principle be more efficient due to less conversion steps and could also be used in phased arrays. Second, the use as an opening switch for an inductive energy storage system is of interest since it would provide higher energy storage density compared to capacitive systems. Third, repetitive operation could provide an efficient means of damaging electronics at medium power microwave (MPM) levels as opposed to HPM.

4.2.2.6 Phased Arrays

Description:
Electronically Scanned Antennas (ESAs) have an advantage over mechanically scanned antennas in that the beam can be rapidly position to any point in its field of view without moving parts. ESAs can be divided into two classes phased arrays and true-time-delay (TTD) beam formers. In a phased array a number of radiating elements are each controlled by a phase shifter for beam steering. All ESAs can be bi-directional in one or multiple dimensions, but to simplify this description of the concept we will reference it to a linear receiver array configuration.

Beam steering direction is determined by applying an incrementing but constant phase shift to each radiating element (i.e. $\phi_2 = 2\phi_1$, $\phi_3 = 3\phi_1$, etc.). In an alternate implementation of a phased array, digital beam forming uses a channelized approach to beam steering. In stead of a phase shifters, the energy is directly sampled behind each radiating element. Beam position of a returned signal is formed in the signal processor.

The other class of ESAs are TTD beam formers. Instead of relying on a phase shifter for beam positioning, they use a structure that varies the delay between radiating elements. An example of this approach is a Rotman lens, which applies optical lens principles in incrementing time delay between elements. The benefit of this approach is a much broader spectrum coverage since the applied delay is independent of frequency. This approach also has the advantage over phased arrays in supporting multi-mode and multi-beam RF applications.

There are two basic approaches to ensuring phase control.

The first is the master oscillator/power amplifier approach, in which a single oscillator provides phase information at low power to amplifiers that generate the final pulses. This configuration has the advantage that phase control is done at low power. An alternative is to control phase on the output end just before radiation, which requires high-power phase shifters (for HPM, current high-power ferrite devices do not approach the required power levels).

The second approach is to lock together the phase of a group of oscillators in a non-linear process. There are several techniques which may be used as follows: 1) priming of the oscillator (i.e. injecting a signal during the start-up phase of the oscillator so that it locks in-phase to the injected signal), 2) prebunching a beam with a phase-locking signal prior to its entry into an output oscillator cavity, and 3) direct injection between strongly coupled oscillators.

<u>Relationship with Radio Frequency Directed Energy Technology Area:</u>
Various high power microwave sources have been developed that produce from 1 - 10 GW peak power. Extension of these sources to higher power levels is being pursued in many laboratories. However there is a concern that higher levels may be inhibited by inherent limits on the electric field sustainable in resonant cavities. Furthermore, the power density limit set by air breakdown argues for distribution of power into an array of radiating antennas. Using a phase-locking approach would allow gigawatt power level sources to be combined, resulting in extremely high power. Phased-arrays could also be used for combining UWB modules.

<u>Availability:</u>
Estimate of technology maturity for full-scale system engineering development:
2010

Impact on military ground force capability:

The concept of phase locking has been demonstrated with experimental systems of several sources. Combining 10 - 100 sources will provide a capability at the tens of GW power level.

4.2.2.7 High-Power Ultra-Wideband (UWB) Microwaves

Description:

The generation of high-power ultra-wideband microwaves can be generated using a variety of techniques. One method is to use a forming line and tesla transformer with thyristor and gas switches. A second is to pulse compression through a Blumlein power forming line and spark gap and oil peaking switches. A technique which has considerable potential is the direct generation of UWB microwaves using photoconductive switches (refer to Underpinning Technology - High-Power Optically Activated Semiconductor Switches). There are several schemes for using this technology:

- Frozen-wave generator: This device uses multiple transmission line sections, arranged in series, with one-way transit times equal to the desired microwave frequency half period, and connected with photoconductive switches. The transmission lines are charged alternately positive and negative to form a 'frozen wave'. Microwave energy is produced when the switches are simultaneously closed to free the frozen wave. The transmission lines are connected to an antenna that radiates the wave.
- Injected wave generator: This device uses a single output transmission line and short parallel line segments connected by photoconductive switches to the transmission line. The line segments are charged with alternate polarities. Closing the photoconductive switches injects waves onto the transmission line. The forward-travelling wave drives the load (antenna) and the backward-travelling wave reflects from the shorted end of the system and follows the forward wave to the load. N injection sites produce N cycles and if the lines are recharged during the burst this results in continuous operation.
- Cavity Modulation: This device uses a pulse line to charge a cavity through a photoconductive switch. The pulse refects back and forth in the resonant cavity because of a short at one end. Due to an impedance mismatch at the open end, a series of pulses of alternating polarity is formed in the cavity. A damped series of pulses is emitted directly from the cavity or coupled out to an antenna. The cavity dimensions set the frequency.

Relationship with Radio Frequency Directed Energy Technology Area:

The generation of UWB microwaves using direct switching provides a capability to produce sequential waveforms of arbitrary temporal characteristics. The development of laser diode arrays (refer to high-energy lasers technology) combined with the photoconductive switching has made possible the development of a compact microwave module with MW power capabilities. The

precision and control of the switches will allow the power combining of these modules into arrays for increased power to the GW level. Beam steering by optically controlled waveform generation should be possible.

Availability:
Estimate of technology maturity for full-scale system engineering development:
2010

Impact on military ground force capability:
The capability of these microwave module arrays with their ability customise pulse(s) in terms of amplitude and/or frequency could provide and efficient means of damaging electronics at medium power microwave (MPM) levels as opposed to HPM. This technology would also be applicable to ultra-wideband radar.

4.3 TECHNOLOGY AREA – COMPUTING TECHNOLOGIES

Introduction:
Command, Control, Communication, Computer and Intelligence are the areas of utmost importance on today's, and even the more, on future battlefields. Due to widespread battlezones and the need for fast reaction, military leadership will only become highly effective if the greatest possible attention is being paid to these capabilities. Therefore ongoing developments in and the application of Data Collecting, Data-Processing and Communication related technologies are of greatest importance.

Key elements are the computer together with the associated software, fast data processing and transmission and human machine interfaces which allow the soldier in the loop to cope with these technologies at their best under battlefield conditions.

In the following, without trying to be exhaustive, underpinning technologies related to selected technology areas are described with a possible outlook to where technology might be going within the next two decades.

It is foreseeable that in most of the developments commercial industries will take the lead. There are, however, areas in military application in which specific endeavours must be undertaken to reach the goal, i.e. in man-machine interfaces, battlezone language software, network management and back-up technologies, etc.

4.3.1 ***Computing Technologies (Artificial Intelligence)***

The existing information processing systems are able to transport, store, compare and process data; i.e. they select and extract information. Future knowledge processing systems (Artificial Intelligence - AI) will be able to relate knowledge (either already installed or self-gathered through sensors) to already stored knowledge and to create new knowledge based on rules and conclusions. Originally, the term AI implied the much more ambitious idea to simulate human intellectual performance. There is no coherent and comprehensive definition of

AI because it changes continually with technological progress.

The so-called expert systems can be regarded as the first stage of knowledge processing systems, which permit query of pre-considered matters in a quasi-natural language and offer certain user guidance in the dialogue.

There is also a reference to the relatively new fields of neurological and biological information processing dealing with information processing procedures and their simulation by computer systems. Especially, the transition from classical sequential information processing to distributed and parallel processing and storage of information neural networks allows computer-based simulation of cognitive functions such as learning, memory and association. An example of AI is "fuzzy logic", a mathematical approach to the description and modelling of vague quantities and data.

Impact on military ground force capability:

Potential advantages of neural network technology are high-speed information processing through massive parallelism, insensitivity to variations in element characteristics, trainability (the ability of the system to learn) and compactness.

Artificial Intelligence will therefore have a major impact on automatic sensor data processing (such as remote sensor systems), image processing, pattern recognition and adaptive signal processing and control. In the future sensors (of smart munitions or surveillance systems) will be able to detect for example, tanks or other armoured vehicles partially hidden or in a complex background.

*4.3.2 **Computer Applications and Information Processing***

The flow of information in preparation for ground warfare and during battle will continue to increase as intelligent sensors, unmanned systems, computer-based communications, and other information-intensive systems proliferate. Data bases and their management software will progress beyond even object-oriented data bases to third-generation data bases with new modes of indexing stored data and more intelligence in interacting with the human user of the data base. Mixed machine-human learning will team the learning capabilities of a person with the rapid data processing and analysis capabilities of a computer.

Battle control language and associated support are needed for computer assisted decision support and battle management. The capacity of computer hardware to process data has grown at a tremendous rate. This capacity is expected to grow two orders of magnitude every decade. The constraint of fuller use of this technology is the development of software programs to carry out the types of analysis required for efficient and reliable intelligence extraction, synoptic organisation of the intelligence, and interpretation of command decisions into detailed directives to the active elements. For battlefield management, this will continue to be the critical area; it will be the pacing factor in implementing an agile force strategy.

Tactical advantage can be gained by having more rapid access to relevant stored data, so that enemy capabilities and the environment are well understood. Advantage can also result from fast simulation systems, so that tactics can be

quickly realigned to seize an unexpected opportunity. A critical requirement exists for all systems' software to function smoothly and seamlessly across the diverse battlefield operating systems, requiring comprehensive attention to data software protocols and standards for all service, joint and combined software systems as well as backwards compatibility with previously fielded editions and systems.

Battle control languages are a layered structure of computer languages. The syntax and semantics of the top-most language duplicate military operational and logistical terminology. Statements in the top-level language will look like map graphics, operations orders, or report formats. A series of intermediate languages will provide the ability to modify software at various levels of abstraction. Battle control languages will enable forces to move data, extract information, compare courses of action and even make automated decisions all without concern for the details of computation. This technology offers capabilities for: simulating and evaluating alternative courses of action; exercising command and control over the battlefield in near real time with accurate and reliable information; providing an unprecedented degree of realism in training exercises and analytical work.

The current limitations to practical application of artificial intelligence to battlefield management may be overcome if an adequate theory of representation can be developed and action-based semantics can be applied to the Army's battlefield information requirements. The information transmission bottleneck on the electronic battlefield also calls for data compression techniques; semantics-based information compression would address this problem by assessing the value of information relative to the cost of transmitting or storing it.

Application of principles of biological information processing should help. Biological systems receive, store, duplicate, respond to, and transmit information. The knowledge we have gained about the mechanisms through which this information processing occurs will find practical application. In the design of information systems, capabilities such as pattern recognition and selective abstraction of relevant data may use principles discovered from biological systems. Biological structures, natural or bioengineered, may be biocoupled with electromechanical and optoelectronic components. At even higher levels of information processing, a growing understanding of the biological basis for learning and memory may provide new models and techniques to improve training and performance for information-intensive tasks.

Impact on military ground force capability:

Computer technology provides rapid, processing assimilation and transmission of data, furnishing a streamlined intelligence to fire support architecture, and advanced decision aids and algorithms for real time battlefield targeting.

Battle management software provides for a common picture of the battlefield shared by all tactical commanders. It will reduce fratricide. It will provide the ability to manoeuvre dispersed while concentrating effects. The use of advanced databases using artificial intelligence decision aids and real time combat intelligence will allow decisive action while increasing survivability.

Battlefield Management Systems will provide precise logistics situational awareness and resource control through advanced decision aid and tracking algorithms.

Information warfare technology will provide the ability to rapidly assess and adapt the operational and tactical plans in response to the real time situation. This will provide commanders the ability to act within the decision cycle of the enemy and operate at a tempo two to three times as fast as is currently possible.

The proliferation of battlefield sensors on combat systems including even the individual soldier, linked to a comprehensive information architecture with highly evolved database management, will allow increased availability of high value combat intelligence and targeting data to the manoeuvre commander. The comprehensive situational awareness resulting will reduce fratricide and provide the ability to move dispersed and survivably, massing combat power only at the critical time and place.

Attacks on the enemy information systems will restrict their ability to control their forces and blind their intelligence systems. Tactical advantage can be gained by affecting the enemy's information system. Slowing the flow of, or denying, information to an enemy's information system can lessen or even negate his combat capability. A more sophisticated approach, but one having greater leverage, is to inject misinformation into the enemy's information system. Although these approaches have always been applicable to warfare, the means of implementing them have changed with the technology of military communications.

4.3.3 ***Computer Technologies***

4.3.3.1 Application Specified Integrated Circuits

Description:

Application Specific Integrated Circuits (ASICs) are used as substitutes for subsystems normally made of standard integrated circuits. ASICs are grouped into three categories: programmable logic devices (PLDs); gate arrays or standard cells; and wafer scale integrated circuits. PLDs are readily available, low cost devices that are electrically programmed or tailored to a specific application. Gate-array and standard cell devices occupy the middle range of capabilities. At the upper end of the spectrum are multichip modules and wafer scale products. ASICs will perform operations (in terms of the number of equivalent gates and "flip flop toggle rate") more efficiently and reliably than a system of non-specified integrated circuits.

Relationship with Computer Technology:

The use of ASICs in a digital system results in fewer components, higher reliability and lower weight, size and power. These attributes provide a tremendous advantage to military systems that are constrained by these same factors.

Availability:
Estimate of technology maturity for full-scale system engineering development:
2000 - 2005

Impact on military ground force capability:
Application Specified Integrated Circuits will have broad impacts on warfare because they offer the potential for reducing the size, weight, power and cost of any military system that makes extended use of digital integrated-circuit components (such as vetronics). Reliability can also be expected to improve because of the smaller number of components and connections required by ASICs. Use of ASICs in place of larger standard integrated processors will allow for the development of lightweight sensor, navigation and communications subsystems useful in such applications as tele-medicine and logistics tracking as well as making larger multi-component systems more cost, weight and size efficient.

4.3.3.2 Teraflop Computers

Description:
Teraflop computers are high-speed computers capable of performing 10^{12} floating point operations per second. Unless logic devices with switching speeds of 10^{-14} s (two orders of magnitude greater than terahertz devices) can be implemented a teraflop computer will require a large number of slower processors operating in parallel. For example, a single processor based on terahertz devices may be able to achieve a computing power of 10^{10} operations per second. So a teraflop computer would require about 100 processors operating in parallel. The technical challenges are to cut the costs and size of giga-and tera-floating point operation computers so they might fit into a weapons package, to make efficient use of parallel and massively parallel computing assets, and to design systems that will allow easier, and hopefully, very low cost advancements in both hardware and software to achieve truly architecture-independent, high-performance computing.

Relationship with Computer Technology:
When integrated with terahertz electronics and switching devices teraflop computers will provide high performance computing several orders of magnitude faster than currently possible.

Availability:
Estimate of technology maturity for full-scale system engineering development:
2010 - 2015

Impact on military ground force capability:
Teraflop computer technology will have its greatest impact on advanced signal processing and automatic target recognition capabilities. Teraflop computers can also have a significant impact on intelligence related processing and battle management systems which require high orders of computational power.

Teraflop computers in conjunction with terahertz electronics technology will provide the basis for an advanced generation of digital systems for such uses as:

- Determination of enemy intentions
- Surveillance of enemy force movement
- Recognition and identification of enemy forces
- And the guidance of weapons by intelligent seekers.

4.3.3.3 Wafer Scale Technology

Description:

Wafer scale technology represents the high end of the Application Specific Integrated Circuit (ASIC) technology. Typical applications of Wafer Scale Technology (WST) utilise circuits as whole systems that are capable of substantial computation. The WST can implement an entire system on a single substrate. WST is being developed for both monolithic and hybrid devices. Hybrid WST offers the advantage of being able to mix and match a variety of chip types onto a single substrate. Monolithic WST has the chips integrated directly into the substrate; it thereby avoids the reliability problem associated with chip to chip bonding.

Relationship with Computer Technology Area:

Wafer Scale Technology reflects an improvement in fabrication technology required in digital systems, and offers size, weight , and power with improved reliability. WST technology can now produce wafers with diameters of 15 cm, with feature size shrinking to less than 1 μm, and a power dissipation of less than 3 W. These improvements combine to yield a computation rate of 50 billion to 100 billion operations per second, at a dissipation of about 25 watts per wafer.

Availability:

Estimate of technology maturity for full-scale system engineering development:
1998 - 2005

Impact on military ground force capability:

Wafer Scale Technology will make practical a variety of military applications, particularly space-based applications that are now beyond reach for reasons of size, weight and power. Although currently expensive to produce, the WST offers massive computational power for select military systems. Future applications can be expected in radar, communications, avionics and electro-optical applications.

4.3.3.4 Terahertz Electronic Devices

Description:

This area of advanced technology encompasses electronic devices capable of amplifying frequencies up to 10^{12} Hertz (terahertz) and of switching digital signals within time intervals on the order of 10^{-12} second (picosecond). These devices will provide a great improvement in speed and sensitivity of digital electronics. Today's best devices approach only gigahertz frequencies (a billion cycles per

second), but a thousand fold increase is forecast.

Relationship with Communications / Computer Technology Area:

Terahertz devices will be the components for electronic systems such as radar, communications, electronic intercept equipment, and weapon guidance/seekers. Such devices will play a role in front-end receivers and transmitters as well as in signal processing and automatic target recognition equipment. Microelectronics, especially terahertz devices will be the heart of future ultra-fast computers. They will be needed for communication systems, data processing and all phases of battle control.

Availability:

Estimate of technology maturity for full-scale system engineering development:
2000 - 2010

Impact on military ground force capability:

The great increase in speed of terahertz devices will vastly increase communications transmission rate as well as computational power. Terahertz electronics technology will provide the basis for an advanced generation of digital systems for such uses as:

- Determination of enemy intentions
- Surveillance of enemy force movement
- Recognition and identification of enemy forces and
- Guidance of weapons by intelligent seekers.

Terahertz devices will make possible new, more capable electronic systems such as radar, communications, and electronic intercept equipment and smart and brilliant weapons. The increase in communications potential alone could revolutionise battlefield C4I systems. This technology's impact will be pervasive in increasing the ability to conduct information warfare and maintain and protect friendly information systems while conducting combat operations.

4.3.3.5 Thin-Layer Semiconductors

Description:

A number of powerful new techniques have been developed for the growth of single-crystal semiconductor layers from the vapour deposition phase of semiconductor fabrication. The techniques include molecular beam epitaxy, organometallic vapour phase epitaxy, and hybrids of these two. These techniques allow deposition of highly uniform layers, not only of elements and binary compounds but also of solid solutions such as gallium aluminium arsenide (GaAlAs) or silicon germanium (SiGe). These capabilities permit the fabrication of extremely complex multilayer structures with properties that differ dramatically from those of any bulk material. These techniques make possible GaAs high-quality layers on silicon substrates as well as quantum-well-strained layer-composites of Group III-V semiconductor materials.

Relationship with Computer Technology Area:

Over the coming years, the ability to provide increasingly sophisticated semiconductors can be expected to improve computer device (processor) performance dramatically. Processors composed of these semiconductors will be vastly more size and weight efficient and more easily integrated into military electronics systems.

Availability:

Estimate of technology maturity for full-scale system engineering development:
2000 - 2010

Impact on military ground force capability:

Thin-layer semiconductors will provide faster and more efficient processing and smaller computer processors for a wide variety of applications. This means more capable smart munitions, better automatic target recognition, more capable battlefield command and control systems and better soldier and crewmember aids (helmet mounted displays, individual computer resources, position navigation systems, etc.). The reduction in size and weight will have a positive impact on mobility, transportability and deployability of military systems. This is true for future vehicular combat systems, aviation and support systems, as well as individual soldier systems.

4.3.4 ***Data Processing, Artificial Intelligence and Software Engineering***

4.3.4.1 Battle Management Software

Description:

The capacity of computer hardware to process data has grown at a tremendous rate. This capacity is expected to grow two orders of magnitude every decade. The constraint of fuller use of this technology is the development of software programs to carry out the types of analysis required for efficient and reliable intelligence extraction, synoptic organisation of the intelligence, and interpretation of command decisions into detailed directives to the active elements. For battlefield management, this will continue to be the critical area; it will be the pacing factor in implementing an agile force strategy. Battle control language and associated support is needed for computer assisted decision support and battle management.

This technology offers capabilities for:

- Simulating and evaluating alternative courses of action
- Exercising command and control over the battlefield in near real time with accurate and reliable information
- Providing an unprecedented degree of realism in training exercises and analytical work

- Of concern, is the requirement for all systems' software to function smoothly and seamlessly across the various battlefield operating systems, requiring comprehensive attention to data software protocols and standards for all service, joint and combined software systems as well as backwards compatibility with previous editions and systems.

Availability:
Estimate of technology maturity for full-scale engineering development: 2000 - 2010

Technology Applications:

- Close Combat: Provision for a common picture of the battlefield shared by all tactical commanders, reduction of fratricide and the ability to move dispersed and concentrate effects at will based upon seamless information management.
- Information Warfare: Battlefield management, combat intelligence and targeting at both operational and tactical levels of conflict. The ability to operate in near real time (NRT) and, potentially, inside the threats decision cycle.
- Logistics: Accurate logistics situational awareness and resources control through advanced decision aid and tracking algorithms.

4.3.4.2 Battle Control Language

Description:
Battle control languages are a layered structure of computer languages. The syntax and semantics of the topmost language duplicate military operational and logistical terminology. Very high level, battle control languages are being designed to simplify control and programming of combat applications and make use and modification of these programs transparent to the user. Statements in the top-level language will look like map graphics, operations orders, or report formats. A series of intermediate languages will provide the ability to modify software at various levels of abstraction. These languages will make programming look like thinking about battle, use limited simplified language where possible, include appropriate mathematical models for battle, will be adaptable and robust and build compatibility and commonality on good theories. An appropriate analogy is spreadsheet applications where the user mirrors business calculations but is actually programming. Battle control languages will enable forces to move data, extract information, compare courses of action an, and even make automated decisions all without concern for the details of computation.

Relationship with Data Processing, Artificial Intelligence, Software Engineering Technology Area:
Current top down programming methodology requires understanding of the problem and a formulation of the solution before writing any code. Battle Control

Language will allow co-ordination of hundreds of computers and human processors in the face of an intelligently innovating enemy by integrating the context of military operations and symbology into the language and its application. This will vastly simplify and facilitate the modification of programming within military C2I systems.

Availability:

Estimate of technology maturity for full-scale system engineering development:
2005 - 2010

Impact on military ground force capability:

Battle control languages will let commanders control, read and summarise nearly instantaneous data flows about unit status and logistics. Continuous simulations and watchdog programs will provide "what if" advice. The commander and his staff will easily modify these to reflect immediate experience and the peculiarities of the unit, enemy and terrain. Historical data will be collected automatically and analysed continuously. Broad mission orders will automatically generate implementing instructions; automata will execute many of these. Intelligence will be correlated and communicated in seconds, and operations orders prepared and transmitted in minutes, therefore reducing a threat planning advantage. The use of battle control languages will streamline the use of C2I systems providing flexibility and adaptability to military systems software, making their use more rapid and robust.

4.3.4.3 Novel Data Management and Manipulation

Description:

This capability requires the following critical technical challenges to be met including:

- developing data models and storage and retrieval architectures capable of handling all modalities of data in a seamless way,
- merging and synchronising time-dependent and non-time-dependent data,
- developing intelligent agents capable of autonomously navigating complex database structures and extracting information for a user,
- developing natural language and other non-parametric interfaces to support "intuitive" access and retrieval of data from the database management systems (DBMSs),
- developing adaptive information distribution techniques based upon context-based as opposed to message-based distribution,
- using the information context for smart distribution over low bandwidth communications in order to selectively control the quantity of information exchanged,
- providing capability to respond to complete information exchange failures, and

- scaling these information distribution techniques to large systems of communications nodes.

Relationship with Data Processing, Artificial Intelligence, Software Engineering:
Providing necessary Information Services Management within the distributed environment requires the development of mechanisms for managing all types of data both on individual hosts as well as across the distributed environment.

Availability:
Estimate of technology maturity for full-scale system engineering development:
2000 - 2010

Impact on military ground force capability:
Knowledge-based access, retrieval, and integration of information will provide automated, smart means of accessing the user's information needs; performing efficient, smart searches for retrieval through distributed, heterogeneous databases; and will present the information in a format to best support user needs. The user can expect immediate focused, multidomain database search and retrieval supplying awareness of force status in near real time (NRT); distributed, real-time database consistent with predictive battlespace planning; distributed database dynamic updates to strategic attack priorities; continuous distributed posting and deconfliction of task/target/time/space/spectrum allocations; and concurrent assessment of shared and excess assets (aircraft sorties, surveillance, weapons, C3 and logistics processing).

4.3.4.4 Distributed Processing

Description:
Ground forces will distribute their computations across thousands and ultimately millions of machines. The level at which a new application can interact with the distributed complex can characterise distributed processing:

- application
- object data bases, messages
- operating systems, network protocols; or
- hardware (processors, links, sensors, effectors)

Today the level of distributed processing is typically the operating system or protocol. By 2020, it should have advanced to the application level. At that point applications will have compatibility in infrastructure and protocols that will allow seamless yet secure access to data/information/functionality across diverse systems throughout the expanded information architecture.

Relationship with Data Processing, Artificial Intelligence, Software Engineering Technology Area:
Interaction at the application level will accomplish distributed sensor fusion, situation assessment, operations planning, and other decision making, based on sophisticated models of time, space, network topology, delays, information

propagation, sensor status and performance, and weapon status and performance. To support this advance will require massively distributed networks down to each soldier, dynamic real time protocols as part of distributed operating systems and distributed object database management systems that support all data accesses and communications by applications.

Availability:

Estimate of technology maturity for full-scale system engineering development:
2000 - 2010

Impact on military ground force capability:

By 2020 distributed processing will provide seamless access through any application to databases and execution programs required by the commander. Access to distributed processing resources will increase a force's computational assets and allow wider access to situational awareness, intelligence and engagement options. Large parts of the distributed system may disappear without warning and still allow functionality or, at least, graceful degradation and continued operation at reduced capacity.

4.3.4.5 Intelligence and Information Systems

Description:

Fundamental difficulties often occur when accessing information from current database systems, especially when information must be gathered from numerous sources and then synthesised together. A goal of work in intelligent information systems is to permit easier, more powerful universal access to information across collections of disparate database systems. Three emerging technologies will help solve this problem:

- intelligent access
- database mediation
- intelligent agents.

Intelligent access includes automated query formulation which can provide a simpler query interface to users which does not require that the user be familiar with the database's schema. Co-operative query answering helps users to cast meaningful queries that access the desired information by explaining what went wrong when a query fails, by adding additional relevant information in response to queries, and helping the user to reformulate the query actually intended.

Database mediation addresses the problem of needing to access information from various data stores. It offers a coherent view over many databases. To a user, the interface (mediator) resembles a single database system, while actually the system consists of a collection of databases over a network. Users can interact with the mediator system, instead of individually interacting with many systems.

Intelligent agents offer a way to automate certain information tasks. These agents are autonomous programs that operate over a distributed information

environment to find the information they need to meet their goals. Intelligent agents can be used to alleviate complex (but somewhat understood) tasks that users may repeatedly encounter.

Availability:

Estimate of technology maturity for full-scale system engineering development:
2010 - 2020

Impact on military ground force capability:

Command and Control

4.3.4.6 Neural Networks

Description:

Neural networks represent an approach to information processing that is inspired by biological systems. Input data are processed in a highly parallel fashion in a network of simple processing elements (neurons) that may be sparsely or densely interconnected. In a neural network, the interconnection topology and the connection strengths determine the function. The promise of neural networks is high-speed information processing through parallelism, robustness to element failures, and direct hardware implementation of networks in very large scale integrated (VLSI) circuits hardware for realisation of compact processors. Certain neural networks can be "trained" to produce desired responses, in a manner somewhat analogous to programming a computer. Neural nets can be described in algorithmic form and programmed on a digital computer; alternatively they can be implemented in analog VLSI circuits, with great advantages in computing speed and compactness.

Relationship with Computer Technology Area:

The potential advantages of neural network technology are high speed information processing through massive parallelism, insensitivity to variations in element characteristics, trainability/adaptability, and (when implemented in VLSI circuit technology) compactness relative to other standard information processing systems. As computer speeds increase, neural network simulation capability will also increase. The emergence of neural network hardware in the form of custom VLSI chips will require an explicit commitment to advancing the state of the technology.

Availability:

Estimate of technology maturity for full-scale system engineering development:
2005 - 2015

Impact on military ground force capability:

Neural network technology could have a major impact on information processing systems of all types in the future, but the impact on military systems could be revolutionary. The advantages of high speed processing in the form of rugged, extremely compact hardware, with little reliance on software are immediately

obvious in the context of such applications as brilliant weapons, autonomous systems and automatic sensor data processing. Image processing, pattern recognition, speech recognition and adaptive signal processing and control are among the early potential applications of neural net hardware.

4.3.5 *Training Simulation and Synthetic Environments*

Description:
As the ability to process larger amounts of information has grown so has the ability to use that processing power to simulate environments. Computer simulation and the graphical display of diverse environments will allow the trainer or commander to develop training and operational scenarios that can be used for instruction, planning and/or rehearsal of virtual missions.

The integration of simulation and operational Combat Information Systems (CIS) allows the real and virtual worlds to touch and provides a linking of, and communication between, simulations and wargames. This can make for an extremely powerful training experience. Incorporation of advanced computing methods - e.g. virtual reality, knowledge-based decision aids, and high fidelity terrain and environmental simulation, provide the next best operational training alternative to combat, without casualties and at vastly reduced costs.

As a training tool, these simulation and communications technologies significantly reduce controller manpower required to perform even large-scale operational experiments and training. Additionally, the integration of advanced databases, data collection and reduction provide unparalleled opportunities for built-in assessments of training, rehearsals, after action reviews and operational experiments. Control of the simulation environment allows for realistic environmental effects, regardless of climate, weather, time of year or time of day.

Availability:
Estimate of technology maturity for full-scale system engineering development:
2005 - 2020

Impact on military ground force capability:

- Compatible models using compliant procedures and protocols will increasingly allow joint operational training between live, constructive simulations and virtual simulators of various services and nations. This training can be accomplished even between elements at different training areas and facilities using long haul, high bandwidth communication links. Any series of environments and terrain could be modelled. Results will be instantly recorded, assessed and later critiqued; sequels and branches could be postulated, evaluated and re-simulated for additional training value if desired.

- Use of virtual and constructive simulation facilities and programs will provide mission rehearsal and battle planning for real world operational missions anywhere in the world. Units will be able to practice manoeuvre on virtual terrain against a realistic threat using high quality, simulated environments that can represent any series of conditions expected. Numerous contingencies can be modelled and experienced. Modelling of branches and sequels can be accomplished not only as a pre-mission planning aid, but as a near-real-time decision support aid to commanders and staff during execution of actual missions. Behaviour during missions can be monitored and if necessary influenced to meet mission requirements.

4.4 *TECHNOLOGY AREA – COMMUNICATION SPECIFIC TECHNOLOGIES*

Introduction:

The main developments in the field of communication technology are to be found in the digitisation of transmissions and switching technology. At the beginning of the 21st century the main applications of document transmission and conference systems between terminals are emerging. It is expected that mobile radio technology will become more and more attractive as data compression progresses. In the local range, the frequency ranges 60 Ghz and 94 Ghz form a reservoir for new radio frequencies. The cross-talk range lies below 1 Km. At the beginning of the next century a service integrating network (ISDN*) -100Mbits/s) will be introduced, which will be able to integrate all types of telecommunications with extremely high data rates. The prerequisite for this development is the standardisation of transmission protocols and interfaces. The so-called Asynchronous Transfer Mode (ATM) was an essential step in this direction.

Advanced satellite communications systems will provide sensory access to all parts of the world. Millimetre-wave and optical communications links to satellites, as well as fibre optic networks, offer the greatest potential for secure high-bandwidth transmission for both long distance and local information distribution. Tactical communications means such as combat net data radios and advanced switching capabilities are being developed to provide secure seamless battlefield data transfer for army tactical information networks. This should increase the ability of commanders to conduct combat identification thereby reducing fratricide and improving speed and tempo of manoeuvre.

Spread-spectrum electromagnetic links to remotely operated air and ground vehicles will also provide the basis for "tele-presence" which enables the intelligence of humans and smart machines to be merged for many applications, including reconnaissance and targeting. The very high bandwidths provided by secure fibre optics systems will permit distribution of sensory and communication information which is key to robustness in distributed processing. Commercial-off-the-shelf (COTS) technologies should be used wherever feasible to rapidly increase capabilities. Always balancing military requirements for encryption and protection of command and control communications.

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*) Integrated Services Digital Network (ISDN)

Technology Applications:
In general, satellite technology, the application of optical wave guides and higher frequencies, as well as digitisation, offer advantages for increased ranges, transmission capabilities, better encryption and resistance to interference.

Advanced digital communications allow transmission of real time, high volume targeting data over streamlined sensor-to-shooter links.

In close combat, near real time, secure transmission of high value combat intelligence including battlefield imagery to tactical commanders will become routine.

Advanced satellite communications systems will allow global distribution of national and operational intelligence, sensory data and imagery in real time to operational and tactical commanders.

Automated digital communications will offer enhanced logistical situational awareness and tracking of critical battlefield resources.

Availability of technologies:

- Optical communication (e.g. through glass fibre supported hetero-dynamic procedures) is applied to wide distances 2000
- Optical transmission over wide distances without relay stations 2005
- Development of multifunctional optical and millimetre wave chips permit super wide band transmissions 2005
- Laser data links are installed between satellites and ground stations 2010
- Development of crypto technology based on quantum nature of light 2010
- Local mobile radio within a range of 60/94 Ghz 2005

4.4.1 ***Monolithic Microwave Integrated Circuits***

Description:
The availability of good quality, highly reliable semiconductor materials such as GaAs and indium phosphide (InP), the development of advanced epitaxial techniques, and improvements in lithographic techniques have made possible microwave and millimetre (10 to 100 Ghz) integrated circuits for small-signal and power applications. Such devices offer significantly greater reliability than the travelling wave tube and vacuum tube microwave amplifiers. MMICs allow the development of advanced communications terminals and satellites and signal intercept systems. Analog integrated circuits employing approximately 500 of these devices with higher densities can be expected to be developed as transceivers of electronic intelligence receivers and communications satellites and terminals.

Relationship with Communications Technology Area:

In the future, MMICs will make possible the development of lightweight phased array radars capable of a variety of sensing and communication functions.

Availability:

Estimate of technology maturity for full-scale system engineering development:
1998 - 2005

Impact on military ground force capability:

Monolithic-Microwave-Integrated-Circuits based millimetre-wavelength communications will provide covert, anti-jam beyond line of sight links between manpack terminals and lightweight (1000 lb.) satellites compatible with military strategic and tactical relay systems. Agile-beam, extremely high frequency (EHF) terminals will provide high performance tactical links from aircraft to aircraft, aircraft to satellite and ground to satellite. These capabilities support the development of responsive tactical communications networks capable of sharing large volumes of digital data. This is expected to be an integral element of the realisation of high quality tactical internets providing robust combat intelligence and responsive sensor to shooter links.

4.4.2 ***Optical Communications and Switching***

Description:

Optical systems are expected to replace much of the traditional electronics for communications technology and information processing. As semiconductor materials and devices play an increasing role in optical and integrated optical systems. Semiconductor materials comprise both active and passive elements in integrated optical structures for optical data. Optical coherence phenomena in quantum-well and other quantum confined materials and bulk semiconductors have revealed light-induced shifts of excitonic resonances. Such optical coherence phenomena, which are particularly suited to high-bit-rate applications where intrinsic absorption can be the limiting factor, will lead to unique, ultra-fast, ultra-energy efficient and highly cost effective optical switches and logic devices for application in all-optical-light-control-by-light optical communications technology and information processing.

Relationship with Computer Technology:

All-optical digital systems for information processing and communications offer the possibility of very high integrity systems, wide bandwidth, high speed, bulk processing, and can be interfaced with electronic elements through integrated optical fabrication technology. Device applications are anticipated which stem from optical coherence phenomena in semiconductors which are particularly suited to high-bit-rate applications where intrinsic absorption can be the limiting factor. The ultra-fast regime of semiconductor laser dynamics is expected to lead to unique, ultra-fast, ultra-energy efficient and highly cost effective optical switches and logic devices for application in all-optical-light-control-by-light optical and integrated optical communications technology and information processing for high-bit-rate logic and multiplexing and optical solitin generation in semiconductor

materials for large bandwidth, high information through-put, and novel semiconductor superfluorescent lasing. Optical soliton generation and propagation in semiconductor materials can facilitate fast logic and multiplexing operations and large bandwidth for high information throughput.

Availability:

Estimate of technology maturity for full-scale system engineering development:
2000-2015

Impact on military ground force capability:

Replacement of electronics with photonics will result in faster, lighter, more compact, and interference-resistant information processing and communications for battlefield and battlefield-support activities. Development of this technology could strongly facilitate high performance computing for embedded systems in future weapons design.

4.4.3 ***Secure Wide-band Communications***

Description:

Communications technology such as millimetre-wave and optical communications links to satellites, and fibre optic networks, offer significant potential for secure high-bandwidth transmission for both long distance and local information distribution. Tactical communications means such as combat net data radios using numerous discrete waveforms and advanced switching capabilities are being developed to provide a secure seamless battlefield data transfer for army tactical information networks. Additionally, the very high bandwidths provided by secure fibre optics systems will permit distribution of sensory and communication information key to robustness in distributed processing systems.

Relationship with Communications Technology Area:

Secure wide-band communications links are critical to the development of operational and tactical information warfare capabilities. Advanced satellite communications systems will provide sensory access to all parts of the world. However, the complex flow of data from space, air and ground sensors requires secure, redundant high-bandwidth communications links, even if local pre-processing occurs at the sensor before data are transmitted.

Availability:

Estimate of technology maturity for full-scale system engineering development:
2000 - 2010

Impact on military ground force capability:

The development of secure wide-band tactical communications systems will provide aviation and fire support assets the capability for transmission of real time, high volume targeting data over streamlined sensor to shooter links. It will provide tactical manoeuvre commanders the backbone of a tactical internet which will provide near real time, secure transmission of high value combat intelligence

including battlefield imagery. In information warfare these systems will be used to provide distribution of operational intelligence, sensory data and imagery in real time. Finally, the network of secure wide-band communications links will provide logistics systems enhanced logistical situational awareness and tracking of critical battlefield resources into and throughout the theatre.

4.4.4 ***Network Management***

Description:
Advanced network management technology provides the warfighter with a Multi Level Security (MLS) communications system that gives user-transparent connectivity for voice and C2I systems data over the entire operational continuum. The system will fully support wide-and narrow-band On the Move (OTM) C2I data/voice interconnections throughout a land battle zone at least 100 kilometres (km) deep and provide robust and seamless connectivity between ground, air, and naval elements of the coalition combat force dispersed over distances up to 200 km. This requires significant enhancement of tactical communications systems, development of automated, seamless, interfaces between tactical systems, and between tactical and global systems; the development of sophisticated new radio and antenna systems for the airborne and ground, OTM portion of the force; the evolution of theatre/global broadcast systems as an element of seamless communications, and the development of artificial intelligence tools for network planning, management, and operations

Relationship with Communications Technology:
A range of transmission media, bandwidths, signal specifications or standards, and protocols must be accommodated automatically by the networks. Voice and all types of data (e.g., text, graphics, imagery, and video) will be handled within a uniform, information transport infrastructure. These will provide the commander with high capacity, flexible, tactical communications to serve all users (including mobile) and satisfy the need for high-confidence communications with anyone regardless of system limitations throughout all phases of the battle.

Availability:
Estimate of technology maturity for full-scale system engineering development:
2000-2010

Impact on military ground force capability:
Network management technology facilitates required force capabilities to include all aspects of information dominance, as well as real-time logistics control. The communications network provided is the mechanism to achieve secure, reliable, timely, survivable, command and control and superior battlefield knowledge. Seamless network management connotes assured, user-transparent, secure connectivity between global locations and positions from theatre down to the lowest echelon foot soldier. Voice and all types of data (e.g., text, graphics, imagery, and video) will be handled within a uniform, information transport infrastructure.

4.4.5 *Micron Sized Vacuum Transistors*

Description:

The development of reliable cold cathodes with high current densities will make possible micron-sized vacuum transistors. These vacuum transistors, which have the same principles of operation as larger vacuum tubes, will have high frequency and high power capabilities not obtainable with any semiconductor. Such vacuum devices will allow the development of radars and communications systems at frequencies and power levels not presently obtainable. These devices can be integrated with present silicon and GaAs technology in unique radar and communication systems.

Relationship with Communications Technology Area:

High frequency, high-powered vacuum transistors could replace the presently used travelling-wave tubes with a substantial reduction of size, weight and power consumption. Such devices could enhance high-resolution radar systems and space based line-of-sight communication systems allowing a great increase in wide-band tactical and strategic communication links.

Availability:

Estimate of technology maturity for full-scale system engineering development:
2000 - 2010

Impact on military ground force capability:

Micron sized vacuum transistors allow smaller, more compact and capable satellite communication systems. These systems should be more affordable and may lead to more application to supporting ground force satellite communications requirements. This technology enables reliable, secure and flexible communications architectures capable of passing high bandwidth data and imagery at both the strategic and tactical level. Application of this technology in satellite systems can provide a significant increase in the capability to support robust radiation resistant communications networks that support ground forces and in the ability of those forces to reliably access critical intelligence, navigation and situational awareness data.

4.4.6 *Multi-Gigahertz Analog to Digital Converters*

Description:

Analog to digital (ADCs) converters are the interface between the analog world and the digital processing systems used to interpret that world. The trend is toward monolithic, multi-step converters rather than flash converters to minimise system size. The commercial sector is driving ADC development with its need for video-rate (10 to 50 MHz) products with modest dynamic ranges (6-8 bits). The advent of high definition TV with its digitally implemented features will increase this direction of research. About the year 2000, multi-gigahertz ADCs will be readily available for specialised commercial applications and high precision (16 bit) ADCs will move into the multi-megahertz range. Military systems, however, require not only high sampling rates but also high dynamic range (12 or more

bits) to accommodate the wide range of signal levels encountered in the military environment. Current research is pushing to develop monolithic products with at least 12 bit resolution and multi-megahertz sampling rates for military applications.

Relationship with Computer Technology Area:

ADCs are a vital element in digital processing systems. As sensor technology expands, either in terms of bandwidth or focal plane size, the need for ADCs with wide-band, high dynamic range continues to grow. As ADC capability expands, system designers have more freedom to exploit advances in sensors and communications systems. For example radar systems can use wide bandwidths, therefore improving the range resolution of the system while reducing probability of intercept.

Availability:

Estimate of technology maturity for full-scale system engineering development:
2000 - 2010

Impact on military ground force capability:

Multi-megahertz ADCs will help overcome the limitations in computational throughput, and cost, power, size, and weight requirements for computers networked with communications and sensors systems. These requirements and limitations impact weapons systems, simulators, and various support systems (intelligence, C2, target acquisition etc.). An example of increased capability would be an expanded ability to find targets and process firing solutions for the air defence weapons defending against a theatre ballistic missile threat. Another example would be faster processing of radar inputs for target acquisition and counter battery fire. Ultimately the increased capability offered by multi-megahertz ADCs results in increased situational awareness and better sensor to shooter linkages.

4.4.7 ***Digital Signal Processing Micro Processor Chips***

Description:

Many modern signal analysis systems are based on a class of processing chips known as digital signal processing (DSP) microprocessors. These integrated circuits are very similar to conventional high performance microprocessors, except that their instruction sets are optimised for signal processing applications such as filtering spectral analysis, and convolution. Over the next five years these chips will follow trends toward smaller size and faster clock rates. The other dimension to be applied will be parallelism. The design of the central processing unit elements will include the communications necessary to exploit the parallelism, a feature lacking in the present generation of DSP chips.

Relationship with Computer Technology Area:

For DSP applications the DSP microprocessor has several distinct advantages over a conventional microprocessor. It not only has a peak computation rate but

also has an architecture that allows it to sustain an average computation rate close to the peak computation rate in a typical DSP task. These chips also have special-purpose input/output ports that allow them to be easily integrated into compact systems. In ten years chips capable of 100 million instructions per second (MIPS), based on application of GaAs, become available for dedicated front-end applications. Fibre optics will provide gigabit inter-processor capability, eliminating communications bottlenecks between processors. Software design methodologies to support the high level of parallelism will also be developed over this period.

Availability:

Estimate of technology maturity for full-scale system engineering development:
2002 - 2011

Impact on military ground force capability:

The chief effect of the new generation of DSP chips will be to increase the sophistication and reduce the size of military systems that exploit signal processing technology, including radar, communications, image processing and reconnaissance systems. Examples of applications include:

- Compact smart weapons with onboard target recognition;
- Advanced low probability of intercept communications techniques; Speech recognition for command and control
- Sophisticated radar systems for the detection of stealth aviation and ground systems.

4.4.8 ***Superconducting Electronics***

Description:

Superconductive microwave circuits will make feasible communications and electronic warfare systems that are more compact and more sensitive. Multi-gigahertz instantaneous bandwidths permit radar range resolution of a few centimetres. High Q resonators make possible Doppler discrimination against clutter and chaff. Wide-band signal processing functions can provide covert, spread spectrum communication and instantaneous spectral analysis of hostile emitters. Superconducting analog pre-processors with very wide bandwidth and using frequency chirp and other networks are likely early applications. Miniature liquid nitrogen coolers weighing 100-200 grams are already available to cool superconducting electronics.

Relationship with Communications Technology Area:

Superconductive digital circuits have the potential to provide for high speed processors that are more compact and operate at lower power. The signal processing functions can impact communications capabilities allowing greatly increased throughput of digital data for operational and tactical communications systems.

Availability:

Estimate of technology maturity for full-scale system engineering development: 2000 - 2010

Impact on military ground force capability:

Superconductive microwave circuits will provide a significant increase in secure radio and data transmission capability for ground forces. The application to wide-band communications will increase the capability to transmit greater volumes of battlefield data reliably. Increases realised will foster the development of responsive tactical architectures for targeting, command and control and intelligence collection. Application to tactical communications could lead to a new generation of capable digital radios with greater reliability and flexibility in transmitting and routing discrete signal traffic allowing ground forces secure, robust and reliable communications over a greatly extended range even during highly mobile operations.

4.5 TECHNOLOGY AREA – ELECTRONIC AND INFORMATION WARFARE

Introduction

Electronic Warfare exploits and denies enemy use of the EM spectrum; it is not a single technology, but integrates many technologies listed elsewhere in this annex. The key challenges are in increasing sensor sensitivity and bandwidths, processing of the collected data, and generation of wideband, high power or coherent jamming waveforms. In addition to these areas, there are specific computer warfare and IW technologies which are discussed below.

Possible attacks in this area may occur anywhere and at any time and will become eminent the more one gets dependent on electronic data base systems. Therefore activities in this area, beside making positive use of all possibilities electronic systems may offer relative to military applications, must heavily be directed towards providing for the utmost security of electronic systems and to seek for possibilities on how to be able to weaken systems of an opponent.

In today's massive data rich environment, military forces will become more and more reliant on the fidelity of information for correct decisions. The capability to hamper the C^4I capabilities of the enemy as well as to provide assurance in the information of our own systems can mean the difference between victory and defeat in the information age. On the other side of the equation is the assurance in our own information base.

Successful implementation of these technologies will allow transparent and secure use of computational assets from the individual soldier with his highly portable processor/communications system to the high value intelligence ground station higher echelon. The keys are to:

- guarantee the availability and integrity of information systems to support the warfighter in a dynamic battlefield environment,
- provide systems to monitor the status of performance and health of the system and to modify allocation of resources to accommodate any changes or anomalous behaviour,

- provide graceful degradation of performance for systems under attack, assuring that as resources are depleted, they are dynamically allocated to the highest priority mission support, and finally to
- provide multi-level security within tactical and operational information systems with integrity and assured service.

4.5.1 ***Computer Warfare Technologies***

Description:

Computer warfare involves at least four components: information security, electronic virus injection, sabotage and modelling and exploiting computational predictability. It includes the preservation of the access control, authentication and integrity of information and the military systems containing information. Functionalities realised are:

- protection of a communications grid against both overt and covert threats,
- mandatory and discretionary access control across multiple levels of classified data, and
- correct, consistent non-corrupted data across multiple distributed databases.

The need for multi level information system security exists in all types of operational systems (e.g., command, control, execution monitoring, and weapon system) as well as all types of support systems (e.g., logistics, transport, etc.). Especially for systems in the battle area, encryption, software-implemented echeloned access and content based access, based on likelihood of compromise, will mitigate the danger. Coded access, psychological monitoring and self-destruct mechanisms may also be implemented.

Relationship with Computer Technology Area:

Provides that degree of control in information functions that permits friendly force's information systems to operate at a given time and place without prohibitive interference by the opposing force.

Availability:

Estimate of technology maturity for full-scale system engineering development:
2000 - 2010

Impact on military ground force capability:

Successful implementation of these technologies will allow transparent and secure use of computational assets from the individual soldier with his highly portable processor/ communications system to the high value intelligence ground station higher echelon.

The keys are:

- to guarantee the availability and integrity of information systems to support the warfighter in a dynamic battlefield environment,
- to provide systems to monitor the status of performance and health of the system and modifies allocation of resources to accommodate any changes or anomalous behaviour,
- to provide graceful degradation of performance for systems under attack, and assures that as resources are depleted, they are dynamically allocated to the highest priority mission support and finally to
- to provide multi-level security (MLS) within tactical and operational information systems with integrity and assured service.

4.5.2 ***Information Warfare (IW)***

Description:

The flow of information in preparation for ground warfare and during battle will continue to increase as intelligent sensors, unmanned systems, computer-based communications, and other information-intensive systems proliferate. Data bases and their management software will progress beyond even object-oriented data bases to third-generation data bases with new modes of indexing stored data and more intelligence in interacting with the human user of the data base. Mixed machine-human learning will team the learning capabilities of a person with the rapid data processing and analysis capabilities of a computer.

The current limitations to practical application of artificial intelligence may be overcome if an adequate theory of representation can be developed and action-based semantics can be applied to the Army's battlefield information requirements. The information transmission bottleneck on the electronic battlefield calls for data compression techniques; semantics-based information compression would address this problem by assessing the value of information relative to the cost of transmitting or storing it.

Application of principles of biological information processing should help. Biological systems receive, store, duplicate, respond to, and transmit information. The knowledge we have gained about the mechanisms through which this information processing occurs will find practical application. In the design of information systems, capabilities such as pattern recognition and selective abstraction of relevant data may use principles discovered from biological systems. Biological structures, natural or bio-engineered, may be bio-coupled with electromechanical and opto-electronic components. At even higher levels of information processing, a growing understanding of the biological basis for learning and memory may provide new models and techniques to improve training and performance for information-intensive tasks.

As the Persian Gulf war demonstrated, both the denial of information to the enemy and the supply of misinformation can greatly affect the outcome on the battlefield. Tactical advantage can be gained by affecting the enemy's information system; slowing the flow of, or denying, information to an enemy's

information system can lessen or even negate his combat capability. A more sophisticated approach, but one having greater leverage, is to inject misinformation into the enemy's information system. Although these approaches have always been applicable to warfare, the means of implementing them have changed with the technology of military communications.

For either approach, tactical advantage can be gained by having more rapid access to relevant stored data, so that enemy capabilities and the environment are well understood. Advantage can also result from fast simulation systems, so that tactics can be quickly realigned to seize an unexpected opportunity.

Availability:

Estimate of technology maturity for full-scale system engineering development: 2010 - 2020

Impact on military ground force capability:

- Fire support: Streamlined intelligence to fire support architecture and advanced decision aids and algorithms for battlefield targeting.
- Close combat: Increased availability of high value combat intelligence and targeting data to the manoeuvre commander.
- Information Warfare: See above.

4.6 TECHNOLOGY AREA – ELECTRONIC DEVICES, SENSORS & MICROMECHANICS

4.6.1 NANOTECHNOLOGY

Introduction:

Some of the greatest recent technology advances have been accomplished in the area of miniaturisation in electronic and mechanical devices and it will remain an emerging technology for the future to come. Even though there is only little direct impact to be observed in military equipment as such it cannot be ignored that there is a growing dependency in weapon systems and equipment for ground forces on such technologies.

Nanothechnology is the technology of micro-electronic components, devices, processors and sensors. Since the invention of the transistor in 1947 it is the greatest growth industry of the 20th century, and probably of all time. In terms of the LO2020 study, nanotechnology is purely an underpinning technology, however it is impossible to underestimate its importance to the battlefield of the future. Quite literally all the modern sensing, computing and communicating technologies depend upon it. In the remainder of this paper some of the more important constituent sub-technologies will be described, emphasising potential future applications. Before so doing, it is instructive to consider some relevant background issues that must be borne in mind when considering possible military applications.

Silicon Fabrication Technology

This is an extremely expensive industry. Current fabrication plants cost $1Bn and this may be expected to rise to $3Bn for 0.18μm devices. This will ultimately mean volume silicon (consumer) microelectronics production will be confined to a few large industrial sources, probably in US and Japan, with Korea providing a third possibility. Future market predictions indicate that by 2020 only 0.25% of silicon micro-electronics will be military specific. General purpose computing (60%) and telecommunications (17%) will be the main markets, with domestic entertainment and automotive applications being particularly strong. This is a potential threat for the military. Unless special arrangements can be entered into with manufacturers, there is a real risk that military specific devices will either not be made, or will be prohibitively expensive. One alternative to guarantee supplies is the DARPA inspired "minifab" which would deliver military specific products in facilities costing "only" say $100M.

Theoretical limits to Silicon Technology

"Moore's Law", which predicts that computing power will double every 18 months also applies to other parameters such as device speed and scale size. Extrapolating this forward indicates that fundamental limits may be reached by about 2010 unless some novel alternative approaches are made. For example, the optical lithography limits around 0.1μm are seen as critical for the 2005 to 2010 time scale. Of the range of alternative lithographic techniques, soft X-ray lithography is probably the most viable for volume production. New metallisation materials will be necessary to address the interconnectivity limitations, for example copper. Scaling of lateral device geometries must be done in conjunction with vertical scaling, implying novel gate dielectric materials and processing techniques such as dual gate (SOI) devices.

Novel silicon microelectronic devices will require novel fabrication techniques, for example: nano-scale devices (single electron, nanocrystalline silicon); optically distributed clocks on a chip using SOI substrates; multi-stacked (3D) devices utilising wafer bonding. In terms of volume manufacturing techniques, such as scanning probe, multiple electron beam and self assembly will have too low a throughput to be adopted in the 2020 timescale.

Related to Nanotechnology are a number of underpinning technologies described hereafter.

4.6.1.1 Electronic Nano-Technology

Description:

The interdisciplinary correlation of electronics, information technology, material science, optics, biochemistry, biotechnology and micromechanics is an essential requirement for the enrichment of future innovative processes and new technological generations by this new basic technology. It can be applied to the field of tailored materials and biotechnological systems. The undisputed leading role however, will be played by microelectronics.

Nano-technology is a term that is being applied to any area where very small elements are being fabricated that have dimensions measured in nanometers (nm), typically less than 100 nm. This could be in any of the chemical or materials areas but for these purposes we shall be describing electronic nano-technology. This refers to the capability of forming "vertical" nanometer thin layers of electronic materials or fabricating lateral features that have nanometer dimensions as defined above. The thin layers are deposited using sophisticated epitaxial techniques with materials such as gallium, arsenide, indium phosphide, silicon carbide, and gallium nitride. The narrow lateral features are generally made using electron beam lithography, which can routinely form features as small as 20 nm. With an extensive application of quantum physics these techniques allow a wide range of new electronic and opto-electronic devices to be designed and fabricated.

<u>Availability:</u>
Estimate of technology maturity for full-scale system engineering development:

- The doping density of semi-conducting material is set up in atomic layers 2005
- Artificially assembled atoms 2010
- Methods for the synthesis of substances on an atomic scale which obtain new functions through it 2010
- Technologies for structure development in atomic dimensions 2010
- Highly sensitive and long-term stable sensors for chemical and biotechnological systems *2005*

<u>Impact on military ground force capability:</u>

- The progressing miniaturisation and integration of self-contained elements will lead to ever more efficient components and systems (such as micro-motors, micro-sensors and materials, the properties of which were defined and subsequently influenced artificially) as well as to micro production methods and the continuous development of the planar silicon technology.
- Apart from ever more compact and efficient electronics units (silicon technology), materials can be developed in the future, which permit the production of high performance weapons.
- Electronics nanotechnology will allow smaller and more easily integrated sensors and electronics and avionics for aviation platforms, much smaller aperture radars for smart munitions and Unmanned Aerial Vehicles (UAVs) and smaller aperture radars for weapons systems fire control on combat vehicles.

- As relates to information warfare electronics, nanotechnology will further replace tubes in radar and electronic warfare applications with high frequency and high power devices. It will allow low voltage radio frequency (RF) circuits for efficient interfacing to new generation low voltage (1.2 volts or less) silicon circuits for use in hand-held digital communications equipment. Electronics nanotechnology will reduce the size and energy draw required for deployable equipment and platform sub-systems.

4.6.1.2 Molecular Electronics

Description:

Molecular electronics encompasses the use of molecular materials in electronic (and opto-electronic) applications, for example liquid crystal displays (LCD), the fabrication of electronic devices at the single molecule scale, molecular diodes, and the use of molecular structures for device self-assembly, in DNA-based computing. Primary features of (organic) molecular electronics include low mobilities, intermolecular hopping conduction mechanism, large device geometries, high voltage, low current operation and slow speeds. Molecular electronic devices are however cheap to fabricate and they can be readily formulated into large, flexible films. Current research fields include organic conductors and superconductors, organic non-linear optics, plastic electronic devices, electrochromic and photochromic materials.

Availability:

Estimate of technology maturity for full-scale engineering development: 2020 +

Impact on military ground force capability:

- Mature present day applications are limited to opto-electronic systems, such as LCDs, spatial light modulators, laser printers and photocopiers. An example of a pure organic-based electronic research system available now is a ring oscillator fabricated by Phillips for application in displays and smart cards/tags. The scale is of the order of mm width devices and operation is only up to a few 100Hz.
- Organic materials formulated as photo-refractive polymers permit the use of electric fields to control the materials' refractive index to provide a one-way glass film for eye protection applications. The materials are easily tuneable to a range of wavelengths, are cheap and robust and can be fabricated in large area, thin, flexible films. They are, however, typically slow to react in low light levels (mS to minutes response), require high controlling, voltages, have poor visible transmission and breakdown at high light levels.
- Molecular computing is a completely novel and potentially revolutionary approach to computing utilising tailored molecules. For example it is possible to exploit the features of DNA molecules; mutual recognition, self-assembly and templated amplification (polymerase chain reaction, PCR) to solve specific problems.

Because of hydrogen bonding in DNA, enzymes can be used to control the bonding, cutting and sequencing of the molecules. DNA comping is massively parallel but it is slow, difficult to re-program and difficult to interface with conventional electronics. Nonetheless, such simple devices as have already been made demonstrate 10^6 times the computing power of the best supercomputers and have very low energy requirements. Encryption and de-encryption may be appropriate problems for this sort of computing technology. In addition, molecular computing is more naturally suited to optoelectronic rather than purely electronic applications. The combination of molecular computing and bio-molecular manipulation hints at truly disruptive potential applications.

4.6.1.3 Conventional Silicon Based Electronics

Description:

The Semiconductor Industry Associations' (SIA) roadmap, based on 'Moores Law', of the microelectronics performance indicates that individual transistor feature sizes will scale to 0.1µm by 2005, reaching the wavelength limitation in optical lithography. Assuming an exponential extrapolation to 2020 transistor devices will tend towards the single electron device and be of the order 250Å. In reality due to fabrication costs and interconnect limitations device geometry's are likely to be roll-off to around 0.05µm.

Circuit complexities are likely to reach 100Gbit DRAMs and microprocessors with between 1G and 10G transistors per chip, by 2020 assuming the same roll-off. Extrapolating the chip size leads to a 4cm square DRAM chip by 2010, and 6cm square by 2020; chip size will be limited by the chip cost. Microprocessor on-chip clock speeds will probably be limited to around 2GHz to 3GHz by 2020.

Chip supply voltages will bottom out at 0.9 volts leading to an increased vulnerability to electromagnetic interference (EMI) and electrostatic damage (ESD). Chips will dissipate more power, reaching 10 Watts beyond 2000 for logic circuits, this will place greater demands on heatsinking in the electronic system as a whole and could lead to circuit reliability problems.

Analogue to digital converters, which are of particular military importance currently achieve around 1Gsps for 8 bit and are likely to reach several 10's of Gsps by 2020.

Availability:

Estimate of technology maturity for full-scale engineering development: Now - 2020

Impact on military ground force capability:

- Battery-powered, portable computing and communications equipment market will drive the requirement for low voltage, low power microelectronics. This may involve new circuit architectures and device technologies, for example silicon-on-insulator (SOI), silicon-germanium (SiGe) CMOS. Major growth areas are: smart

power, incorporating power devices and digital control (electric vehicles), system on a chip and RF CMOS.

- There are no likely technical limitations to the developments in chips for data conversion, processing and storage over the 2010 time scale. However beyond 2010 to 2020 there are some severe technical limitations which will slow chip development, notably the economics of novel lithographic techniques for volume production, on-chip interconnectivity and device architectures beyond 0.1µm. Additionally there are likely to be limitations in the application of future circuits due to RF sensitivities and device reliabilities.

4.6.1.4 Conventional III-V based Electronics

Description:

Gallium Arsenide (GaAs), Indium Phosphide (InP), Silicon Carbide (SiC) and Gallium Nitride (GaN) are most well known III-V semiconductors. In general, these are preferred to Silicon for high power, high frequency applications, such as radar, microwave communications and EW.

Analogue devices - Monolithic Microwave Integrated Circuits (MMICs) are analogue devices combining amplifiers, oscillators, mixers and power amplifiers on a single chip, albeit much less complex than a Silicon based counterpart would be. Such systems are currently available; and future benefits will arise from device scaling, novel structures, new epitaxial materials growth and complexity, all leading to increased operating frequencies.

Examples of state of the art multifunctional MMICs (system on a chip) include: 36GHz-receiver module for applications in air/air data communications; 77GHz GaAs (HEMT) chip set for automotive radar in volume production. Future developments are likely to lead to multifunctional MMIC chips operating around 100ghz.

Field effect transistors (FET) as a fundamental circuit element currently achieve speeds of 20GHz with state of art feature sizes (0.5µm), high electron mobility transistors (PHEMT) currently achieve f_{max} of 400GHz (InP at 0.1µm) and f_T of 140GHz (AlGaAs at 0.1µm). In circuit terms these performances relate to a 3 stage low noise amplifier (LNA) operating at 100GHz, 4dB noise factor, 18dB gain, 20mW power, and a 2 stage LNA operating at 110GHz, 4dB noise factor, 18dB gain, respectively.

Power transistors are capable of achieving: 50 Watts for a 1.0µm FET at 1GHz (mobile communications base station); 10 Watts for an HBT at 10 to 15GHz (airborne intercept radar); 5 Watts for a 0.25µm PHEMT at 6 to 18GHz (electronic warfare); 0.25 Watt for a 0.1µm PHEMT at 60GHz (covert communications). Silicon carbide (SiC) and Gallium nitride (GaN) are seen as potential new materials for future power devices due to their higher breakdown voltages. Currently under development this technology should lead to several times the current power levels.

Digital devices

High speed III-V digital components have applications in (IFM), direct digital synthesis (DDS), spread spectrum and code division multiple access (CDMA), digital transmit/receive (T/R) modules, digital radio, realising bandwidth for optical communications. Examples of state of art chips included an HBT-based 12 bit, 2GHz digital to analogue converter (DAC) for DDS, HEMT-based 15GHz phase locked loop (PLL) for frequency synthesis, 40Gbps pre-scalers for optical fibre communications and a 6 bit, 4Gsps ADC. For high speed digital VLSI although III-V technology currently achieves better frequency performance than conventional silicon it will be in direct competition with advanced silicon and SiGe technologies.

Availability:

Estimate of technology maturity for full-scale engineering development:

III-V devices are already available and it is expected that performance improvements will continue until 2020 and beyond.

Impact on military ground force capability:

In addition to the applications described above, an area of importance for the future is in opto-microwave where on-chip optical components are employed to exceed the performance of pure electronic circuits. Optical components including modulated solid-state lasers, modulators, detectors, amplifiers could be combined with on-chip wave guides, dividers etc. for applications in wide bandwidth low loss transmission for antenna remoting, optical feeds for phased array radar and beam steering for wide band array antennas. Future developments in production over the 2020 time scale are likely to include selective area growth to permit a wider range of electronic and optical functions.

As with silicon technology, the drivers for higher operating frequency at lower powers will lead to one of the key issues in the future being linearity effects and vulnerability of electronic systems to RF communications environment and RF weapons.

A key issue for military access to III-V technology production is the need to align the production routes for MMIC-based electronic systems between military applications and commercial industry.

4.6.1.5 New Electronic Devices - Indium Antimonide (InSb)

Description:

In many ways, Indium Antimonide is the ideal semiconductor material. It has an electron carrier mobility 50 times that of silicon (10 times that of GaAs), a saturation velocity 5 times that for silicon and GaAs, and a long mean free path. The combination of these properties would ultimately lead to electronic devices with potentially low operating voltages (hence low power), very high-speed operation and low noise. These are key benefits for future portable, low power military electronic systems. Additionally the material is direct bandgap leading to the potential realisation of on-chip optical functions (inter-chip communications). So far, it has been primarily researched for IR applications where cooling is

required. However for the material to be useful for Microelectronic functions carrier control is required to reduce severe leakage problems due to the high intrinsic carrier levels. This problem has been solved uniquely by DERA in the UK, leading the way to the exploitation of this technology for military benefit in the fields of mm-wave (mmW) imaging and radar, and communications (utilising low noise properties), ADCs and very high speed digital signal processing and computing.

Availability:
Estimate of technology maturity for full-scale engineering development: 2020

Impact on military ground force capability:

- So far no circuits have been demonstrated based on InSb, however discrete (1.0µm) transistor device characteristics include initial f_T values of 25GHz, with extracted intrinsic performances of 60 to 80GHz. Simulated future devices are predicted to achieve f_T values of 150GHz. Typically these devices would be expected to operate between 0.5 and 0.1 volts supply dependent on gate length. These figures approximate to a factor of 8 increase in f_T and a factor of 10 decrease in supply voltage compared with silicon.
- There is probably a commercial market for discrete devices, for example high-speed front ends in satellite communications subsystems. The next step is to establish links into a major commercial III-V manufacturing facility, to determine whether the processing is compatible with III-V manufacturing. These links would then in principle provide the opportunity to access this technology via commercial industry. Key issues for future InSb technology lie in the ability to be able to adequately isolate devices on the conducting substrate. This is critical to reduce device leakages and to enable the realisation of circuits.

4.6.1.6 New Electronic Devices - Nanoscale Electronics

Description:
If the current trends in silicon based microelectronic devices follow the current trend, device scale lengths below 0.1µm will be attained by around 2005 to 2010. At this point, the devices themselves begin to converge toward being of single electron control. The single electron transistor (SET) is a true nanoscale device and relies on the action of holding and releasing a single electron in a structure through coulombic and quantum effects. Because such devices would use only a single electron, SET technology offers potentially the highest possible packing density and very lowest power consumption of any microelectronic technology.

Availability:
Estimate of technology maturity for full-scale engineering development: 2020 and beyond.

Impact on military ground force capability:

- Given the immaturity of this field, it is difficult to be certain of future applications, however areas to consider include high density, very low power logic (3 orders of magnitude higher than silicon), highly stable and tuneable current sources, sensitive detectors, low threshold lasers and high density disk storage (electrons written on a metal particle). State of art demonstration devices currently includes an 8x8 memory cell operating at 77K, electrometers at 4.2K and single electron memory cells at 4.2K.
- The key issues lie in the manufacturability of such devices and device reliability due to their inherent sensitivity to small charges and their cooling requirements for operation. For room temperature operation the scale of devices is likely to be around 4nm. Control in the fabrication of nanoscale devices may be achieved using silicon and silicon dioxide layers (common to silicon fabrication) to derive the necessary electron confinement in SETs.

4.6.1.7 High Temperature Superconductivity

Description:

High temperature superconductors (HTS) have extremely useful properties which make them suitable for very high speed, low power electronics, high power and magnetic sensor, and thermal imaging applications. They do however require cooling. There is no current HTS industry as such, the level of maturity is at the stage of demonstrator circuits for a number of specific applications, for example switched filter banks, high sensitivity receiver, chirp filters.

Availability:

Estimate of technology maturity for full-scale engineering development: Devices based on HTS will be available in the 2010 - 2020 timeframe.

Impact on military ground force capability:

- Passive microwave applications include high Q resonators, agile, tuneable filters (to permit selectivity of narrow bands in radar receivers) beam steering networks and receivers (including high performance front-end filters).
- Sensitive thermal imaging in both the IR and mm-wave will be possible using this technology.
- Magnetic sensors (superconducting quantum interference devices, SQUIDs) based on superconductors provide the highest sensitivity to magnetic field, HTS devices being approximately 3 orders of magnitude more sensitive than fluxgates. Potential applications include: submarine detection, land mine detection, NQR explosives detection and munitions fusing.

- Single flux quantum logic (SFQ), whereby a flux quantum is used as a bit of logic, is seen as a means of achieving very high speed and low power electronic functions. By way of comparison with the silicon (SIA) roadmap, by 2005 LTS devices with 0.5µm geometry will have logic circuit clocking frequencies of around several 100GHz. This frequency is about two orders of magnitude above that predicted for silicon.
- Other applications are mentioned under section on Superconductivity.

It is extremely difficult to predict the growth of this technology and thereby it's future availability and application to military systems. There is a substantial market growth predicted in the US for rural cellular telephone base stations that may require superconductor devices. The need for cooling will not necessarily drive generic cooling technology, cooling requirements are application specific.

4.6.2 ***Sensors***

<u>Introduction:</u>

- Smart technologies are concerned with introducing into materials the ability to sense their environment and react in a beneficial way which has been designed-in. This is a long-term goal.
- Enhanced structural monitoring systems will be particularly valuable for weight sensitive critical structures. These may be subjected to high loadings or damage or other environmental extremes. Monitoring should reduce maintenance costs and increase availability. The techniques should be applicable to may systems employed in the battlefield including vehicles and weapon systems, buildings and bridges, UMAs and helicopters.
- Advanced sensor systems could be used for fully distributed fire detection for buildings and large vehicles, detection of vehicles and personnel. Equipment in storage could be monitored to ensure rapid deployment. Other applications could include chemical sensors for atmosphere monitoring in fighting vehicles or for vehicle detection. There should also be applications in smart weapons and mine detection.
- The combination of enhanced sensor systems and actuators offers the possibility of producing systems that can accommodate damage by active compensation and/or reconfiguration. This requires the structure to be controlled as part of the total system. It could enhance the survivability of equipment, e.g. structures for communication links, or surveillance UMAs.
- Other possible applications include novel approaches to identification-friend or foe systems and personnel protection.

Evolutionary performance gains that can be expected from the current research programmes:

- Improved sensors for monitoring strain and temperature and for detecting and locating damage in composite materials. Will enable better utilisation of structures by helping to eliminate unnecessary conservatism in design. Will reduce maintenance costs, particularly those associated with inspection. Will provide sensors that are immune to electromagnetic interference.
- Sensors capable of monitoring equipment in storage, which can be interrogated remotely without disturbing the packaging.

Possible revolutionary performance gains that may be available 2020 and beyond:

- Ability to compensate/reconfigure structures to cope with damage, e.g. communications systems.
- Use of sensors in armoured vehicles to provide inputs to DAS
- Reduce the requirement for reliability, availability and maintenance by taking the man out of the loop.
- Signature control.
- Actuation systems for miniature robots.
- Self-deploying systems for gap crossing.
- Autonomous robotic flying machines, wasps - lots of cheap intelligent weapons.
- Structural control of gun barrels, bridges, mine clearance.
- Health monitoring.
- IR signature control.
- Miniature power supplies
- Safe munitions, self-destructing mines

This list could easily be enlarged by a number of other possible applications of sensors and actuators in systems deployed by ground forces.

4.6.2.1 Multi-Domain Smart Sensors

Description:

The Multi-Domain Smart Sensor (MDSS) will combine visual and multi-band IR imagery with active, eye-safe Laser Radar (LADAR) in a single package. It will be an upgrade of current generation Forward Looking Infra-Red (FLIRS) and night vision equipment. In the 2020 time frame, the subsequent generation of MDSS is expected to include imaging millimetre wave (MMW), visual, mid-and-far IR, and imaging LADAR capabilities, without the need for cryogenic cooling. In addition, the MDSS will incorporate "one-chip" processing which digests the multi-spectral data. Also, it will target shapes and motion to flag regions of

interest for the system operator in real time, thereby reducing his workload while increasing threat detection and characterisation ranges. Size, weight, and power requirements for such systems will be substantially less than that required today for the individual band sensors, such as the second generation FLIR. In the 2020 time frame, we envision a horizontally integrated family of miniature MDSS for Army ground combat platforms, as well as for the individual soldier. This will expand the detection and identification envelope for conventional as well as low observable threats and friendly forces.

Availability:
Estimate of technology maturity for full-scale system engineering development:

- Initial deployment of MDSS 2006
- Second generation MDSS (MMW, visual, mid-and-far IR, imaging LADAR capabilities, w/o cryogenic cooling) 2016

Impact on military ground force capability:

- Close Combat: The multi-spectral active/passive nature of the MDSS will provide high quality, imagery of opposing "low observable" and/or camouflaged threats. It is impractical to suppress target signatures in all bands - visible, active laser (3-5 microns), mid-IR, far-IR, and MMW simultaneously, particularly since MDSS units could be located with advanced radars which are themselves frequency diverse.
- Survivability: MDSS technologies will be compatible with the integration of chemical and biological attack sensor capabilities together with night vision and FLIR equipment.

4.6.2.2 Micro Electro-Mechanical Systems

Description:
Micro-electrical mechanical systems or MEMS are a recent development that have captured the public imagination. The more spectacular MEMS possibilities, such as Silicon Insects feature in newspapers while most people will have seen the TIME magazine cover of an ant "holding" a MEMS gearwheel. However it is one thing to fabricate a nano-scale gearwheel out of silicon and quite another to integrate a set of such components into a miniature version of a full scale machine. Such developments may well be possible, but it is not likely that they will lead to fieldable military systems by 2020. Major benefits from MEMS technology can be expected, but these are more likely to arise from much simpler applications, in particular where there is a strong commercial market that will drive the necessary manufacturing infrastructure.

MEMS are integrated micro-sensors and micro-actuators that provide programmable electromechanical systems that are low cost, low size, low weight, and low power; all attributes of special importance to a soldier. MEMS is an emerging technology that is expected to have technological impact spanning decades. The methods by which the mechanical components are micro-machined and constructed are an outgrowth of the materials and processes

developed by the semiconductor industry for the fabrication of microelectronics, thereby conveying the advantages of miniaturisation and economies of scale for multiplicity and affordability.

MEMS technology is mature enough now for some systems to go into Full Scale Engineering Development (FSED). Additional MEMS will be ready for FSED over the next decade, as new MEMS emerge from R&D. This technology is pervasive as it spans the whole field of sensors, promising miniaturisation and reduced cost with equivalent or improved performance and new military capabilities.

For military applications MEMS could be used in

- platforms such as health monitoring systems or actuators of one sort or another, increasing their efficiency and contributing generally to overall effectiveness,
- information gathering devices,
- artillery with each device equipped with two or three sensors, together with on-board processing, which could be acoustic, smell, magnetic, and IR,
- communication that would be short range, using packet radio techniques at say 60Ghz to be covert (At this frequency the wavelength is 5 mm, so a chip size antenna is possible),
- artificial intelligence techniques that would be used to combine (possibly low quality) basic sensor data to achieve high confidence of detecting enemy vehicles or personnel,
- GPS on a chip to identify location,
- in Miniature UAVs with 10cm wingspan, powered by miniature jet engines and carrying miniature surveillance cameras are one of the more fanciful suggested applications for MEMS, and
- MEMS can be used as a weapon to attack electronics, command and control, and infrastructure control systems.
- in electronic noses, where detection of trace quantities of explosives by combined biological and electronic systems, based on enzymes and antibodies is possible, or even for gas recognition,
- for the detection of Biological Warfare Agents where it is the aim for such a "laboratory on a chip" to replace current systems for detecting and recognising biological agents by its DNA as the key technique such as Oligo arrays in which a large number (10,000) gene probes are embedded within a single chip forming the basis for identification..

<u>Availability:</u>
Estimate of technology maturity for full-scale system engineering development: now - 2010, possibly 2020 and beyond.

Impact on military ground force capability:

MEMS technology can be used to enhance situational awareness through improved integration of system's sensors. MEMs can improve the systems integration and performance of: mass data storage, displays, miniature analytical instruments, identification friend or foe devices, biomedical devices, weapon safing, arming & fuzing, weapons guidance, platform stabilisation devices, navigation, active structures, logistics, aviation and other instrumentation. MEMS can allow for the neutralisation of the principle infrastructure of the opposite forces within ethical constraints.

4.7 TECHNOLOGY AREA - BIOTECHNOLOGY

Introduction:

Biotechnology implies the synthesis of biochemistry, microbiology and engineering sciences. The basis of modern biotechnology is the knowledge of the molecular basis of cellular functions, the possibility of their manipulation and the application of genetic engineering methods.

The successes of biotechnology have been in medicine, agriculture, and bioproduction of speciality natural chemicals. Applications that could be developed and fielded in the 2010-2030 time frame include: deployable bioproduction of military supplies, biosensor systems, enhanced immunocompetence (resistance to disease and many chemical, toxin, or biological warfare agents) for personnel, novel materials with design-specified properties, battlefield diagnostic and therapeutic systems, performance-enhancing compounds, and bionic systems.

Gene technologies are methods to modify the genetic material inside cells. As knowledge of specific genes and their interactions increases, the techniques of recombinant DNA, cell fusion, and gene splicing will enable the transfer of multigene complex characteristics into cells and organisms. New substances and organisms with new properties will be produced, such as substances for discrete recognition of a particular organism or substance, compounds that modify biological responses, artificial body fluids and prosthetic materials, new foods, and organisms for decontamination.

Ongoing developments in biotechnology use DNA chips that can find genetic variations in individuals in order to identify one's specific SNP's (Single Nucleotide Polymorphisms). Variations in the SNP-profile may allow tailoring individual medication that gives the best results, for specific diseases (or effects of biological or chemical agents) that an individual has contracted.

The gene-sequencing technology available in 2020 will allow a less than one-hour estimation of the individual DNA signature, therefor improving cure possibilities in the future battlespace.

Biomolecular engineering will use knowledge of molecular structure to create novel materials with specified properties and functions.

Bioproduction technology uses living cells to manufacture products in usable quantities. The methods can range from fermentation, which has long been used, to multistage bioreactors.

Targeted delivery systems are composites of biomolecules that have been structured to deliver an active chemical or biological agent to a specific site in the body before releasing it from the composite. They will be used for drug and vaccine delivery systems, special foods and diet supplements, decontamination, and regenerating or replacing tissues and organs.

Biocoupling and Bioelectronics will link biomolecules or combinations of them to electronic, photonic, or mechanical systems. The discrete-recognition molecules developed through gene technology will have to be biocoupled to such devices to be useful as biosensor systems. Bionics is the technology for emulating the functioning of a living system with engineered materials. It will progress from current successes in imitating a specific biological material to eventual creation of complex, cybernetic systems that emulate the neural systems of animal behaviour.

Biotechnology offers advantages over more traditional engineering and manufacturing methods for creating extremely complex substances in pure form and for very compact systems engineered at the molecular level. Exploiting the potential of biotechnology will require multi-disciplinary research teams, with competence in physics, chemistry, biology, medicine, and engineering.

In-field diagnostic and therapeutic systems will reduce casualties due to disease and chemical, toxin, or biological warfare threats. Gene technologies, biomolecular engineering, bioproduction technology, targeted delivery systems, and biocoupling technology will all be required. Extended human performance refers to direct coupling of the human central nervous system to machines and other uses of bionics and orthopaedics. Required investments would be in gene technologies, biocoupling, and bionics.

Biotechnologies are emerging technologies which will become available more and more from now to the 2020 timeframe and beyond. Descriptions of such technologies are being given as follows:

4.7.1 ***Gene Technologies***

Description:

Gene technologies are methods to modify the genetic material inside cells. As knowledge of specific genes and their interactions increases, the techniques of recombinant DeoxyriboNucleic Acid (DNA), cell fusion, and gene splicing will enable the transfer of multigene complex characteristics into cells and organisms. New substances and organisms with new properties will be produced, such as substances for discrete recognition of a particular organism or substance, compounds that modify biological responses, artificial body fluids and prosthetic materials, new foods, and organisms for decontamination.

Embedded in the inherited information of every organism (i.e., in its genome), is highly specific information on the molecular sequences of its component biomolecules. Biotechnology can exploit this information to design and assemble

biological molecules and structures that can distinguish unequivocally between Chemical, Toxin, and Biological Warfare (CTBW) agents and nonagents with similar characteristics. Gene technologies (along with the medical and biological understanding they have produced), biomolecular engineering, and biocoupling will be able to move CTBW detection and identification into the next generation of defensive strategies and beyond.

Availability:
Estimate of Technology Maturity For Full Scale Engineering Development:
For biosensors and ability to distinguish between CTBW agents. 2000 - 2010

Impact on military ground force capability:
Fewer chemical, toxin and biological warfare casualties.

4.7.2 ***Biomolecular Engineering***

Description:

Biomolecular engineering is the technology to design and produce biomolecules, including structural proteins, enzymes, etc., with specific tailorable properties. Our current capability to relate the structure of biomolecules to their function is limited for all but the smallest of these molecules. There are still many surprises and predictive failures, even in areas where predictive methods are most advanced. At present we lack the ability to design de novo a biomolecule for a reasonably complex function, such as radar nonreflectivity. However, the scientific disciplines to pursue such a capability do exist.

Progress in biomolecular engineering will depend on advances in two contributing areas:

- prediction of the biomolecular structures required to achieve a desired function and
- methods to design, construct, and produce molecules or composites that meet specific functional requirements. The multidisciplinary research teams needed for this work must combine expertise in structure-function physical chemistry; physical biochemistry; computational methods for simulation, modelling, and display of biomolecules; analytical methods for determining the detailed structure of biomolecules; biophysics and chemistry of molecular biopolymer synthesis; and the biochemistry and molecular genetics of the genome.

Of the several high-payoff opportunities identified in biotechnology, biomolecular engineering will be applicable to the following: deployable bioproduction of military supplies, biosensor systems, novel materials, extended human performance, and anti-materiel products.

Availability:
Estimate of Technology Maturity For Full Scale Engineering Development: 2010 - 2020

Impact on military ground force capability:
Biomolecular engineering offers advantages over more traditional engineering and manufacturing methods for creating extremely complex substances in pure form and for very compact systems engineered at the molecular level.

4.7.3 ***Bioproduction Technologies***

Description:

The bioproduction techniques and resources already available include bioreactors; cell culture and fermentation techniques; cell growth media and factors; established cell lines for mammalian, insect, bacterial, yeast, and algal cells; cell harvesting and processing techniques; chemical coupling techniques and processes for immobilizing (fixing) cells and proteins; and techniques for purification and isolation, such as affinity chromatography.

Further development of fermentation and cell culture techniques, cell lines, and bioreactors will be particularly important for efficient large-scale production. Bioproduction methods also need to be scaled up from laboratory size to industrial production scales.

Affinity chromatography is based on the covalent coupling of affinity ligands, enzymes, and other biomolecules with specific recognition characteristics to inert, solid support materials. The resulting technology will enable rapid, efficient purification and processing of ultrapure materials on a large scale. In one type of purification (monoclonal antibodies), the older technology of column chromatography had a process yield of only 40 to 60 percent, gave a product that was 95 percent pure, and required 2 to 3 days. The new method based on membrane affinity can process the same amount of material in 1 hour, giving a 90 to 96 percent yield and a product that is 99 percent pure.

Bioproduction technology will be applicable to five selected high payoff opportunities: deployable bioproduction of military supplies, enhanced immunocompetence, novel materials, in-field medical diagnosis and treatment, and antimaterial products.

Availability:
Estimate of Technology Maturity For Full Scale Engineering Development: 2010 - 2020.

Impact on military ground force capability:
Bioproduction technologies will be able to produce both natural and artificial materials, such as composites and customised polymers with specifiable physical, chemical, and electrical properties. Advances will depend on the simultaneous development of computer-aided biomolecular design and low-

temperature manufacturing techniques. In 20 years, composite materials may exist that incorporate Chemical, Toxin, & Biological Warfare (CTBW) barriers, special impedance-matching characteristics to attenuate blast and sonic interactions, and some defence against white phosphorous munitions.

4.7.4 ***Targeted Delivery Systems***

Description:

In a targeted delivery system, an active substance is encapsulated in a membrane or a matrix that permits controlled release when the capsule system reaches its intended site of action. The release may be slow, by diffusion out of the encapsulating material, or triggered by dissolution of the capsule. Thus, these systems permit the use of biosubstances that would otherwise be inactivated or degraded before they could be effective for their intended purpose.

New microencapsulation technology, using biomaterials that are biocompatible and biodegradable, will protect sensitive active substances from degradation or inactivation by light, chemical, or biological stresses. In medical applications, drugs, vaccines, peptides, and proteins will be administered with microencapsulation systems now under development. In nonmedical applications, field-deployable, stable capsule systems will be useful for intelligent biosensors, decontamination systems, and biocamouflage systems for signal suppression.

Among the potential applications of interest to the Army are drug and vaccine delivery systems for prophylaxis or treatment of infectious diseases or Chemical, Toxin, & Biological Warfare (CTBW) agents, energy-rich or performance-enhancing foods and supplements, decontamination methods, deployable purification kits, and regeneration or replacement of tissues and organs.

Advances in this area are projected that will produce self-regulating delivery systems. Specific triggering mechanisms for release of the active substance will be developed, such as triggers by pH, ionic strength, specific receptor/ligand binding, or specific frequencies of electromagnetic radiation.

Of the high-payoff opportunities for biotechnology, targeted delivery systems could play a role in enhanced immunocompetence, novel materials, in-field medical diagnosis and treatment, and anti-materiel products.

Availability:

Estimate of Technology Maturity For Full-Scale Engineering Development: 2010 – 2020

Impact on military ground force capability:

Targeted delivery systems will be used for drug and vaccine delivery systems, special foods and diet supplements, decontamination, and regenerating or replacing tissues and organs.

4.7.5 ***Biocoupling & Bioelectronics***

Description:

For near-term biosensor applications and longer term bioelectronics, it is necessary to develop techniques to couple the biocapture and recognition event (the response of a biomolecule to its target molecule or energy form) to the means for amplifying, transducing, and communicating that information into an electronic, optical, or mechanical signal. Development of antibody or biorecepter molecules as biosensors is in progress. The coupling technology is less advanced, receives less attention, and will be more difficult.

Bioelectronics refers to the use of biomolecules or biosensor systems within an electronic data-processing system--for example, a "microchip" integrated circuit that incorporates biosensor elements into a computer memory "biochip". The development of this technology depends not only on biocoupling advances but also on biomolecular elements with a binary signal response.

As with biomolecular engineering, to reap the potential of biocoupling technology will require multidisciplinary teams competent in many specialities, including molecular genetics, receptor physiology, and pharmacology; physical chemistry of macromolecules; the physics and chemistry of signal trapping and recognition; engineering adaptation of unit-event signals into systems with integrated outputs; and engineering to adapt the environment required by the biosensor to the sampled environment.

It is recommended that biocoupling be pursued in parallel with biosensor development, because biocoupling methods may determine which biomolecular mechanisms are feasible as biosensors within the larger system to which they are coupled.

Availability:

Estimate of Technology Maturity For Full Scale Engineering Development: 2010 - 2020

Impact on military ground force capability:

- Deployable remote detection and analysis systems (with telemetry) to assess the presence and status of hostile troops and equipment, disease, and Chemical, Toxin, Biological Warfare (CTBW) threats, or environmental parameters;
- Rapid diagnosis and identification of disease and CTBW threats in the field;
- Terrain and perimeter monitoring;
- Monitoring of critical personnel performance;
- Performance modification (see also bionics technology);
- Bioelectronics identification of friend, foe, or neutral personnel through specialised sensors.

4.8 TECHNOLOGY AREA – ADVANCED MATERIALS AND SMART STRUCTURES

Introduction:

Over the next 30 years, there exists a high probability for unprecedented developments in materials and the blurring of a clear distinction between synthetic and biological materials. For the first time, materials will be designed and synthesised atom by atom for specific applications. There is reason to believe that materials properties will continue to advance exponentially as they have over the past 10-15 years: specific strength and stiffness of composites; flux magnetisation product of permanent magnets; optical transparency of glass fibres; and critical temperature of superconductors are a few current examples.

Designer-engineers using fundamental scientific relations between a structure and its functional capabilities will design future new materials at the molecular level for specific purposes. The realm of engineered chemicals will include both surface catalysts and enzyme-like catalytic molecules, whose specificity depends on their three-dimensional conformation.

There is a trend towards materials design through computational physics and chemistry. This trend combines, within the field of materials science, two other trends: the growth of computer simulation and the design of useful products by application of fundamental relations between structure and function. For materials design, these structure-function relations include interatomic forces, phase stability relations, and the reaction kinetics that determine how complex processes evolve. Possibilities of interest to Army forces include lightweight (half the density of steel) ductile intermetallics, new energetic materials superior to current explosives and propellants in energy density and safety, materials harder than diamond, and tough polymers with working ranges extending to 500 degrees Centigrade (Celsius).

Hybrid materials (also called composite materials) are especially attractive for Army applications because they can be designed for unique and special requirements. For example, the component phases of a hybrid can by altered, or the formation process can be modified, to improve performance in two or more dissimilar functions. The area of greatest technical novelty is that of smart structures. A network of sensors embedded in the structural phase of the composite acts like the sensory nerves of an animal's nervous system. A network of actuators allows properties of the structure to be altered, under the control of a microprocessor that reacts to the sensor signals, analogous to an animal brain.

In regard to advanced manufacturing and processing, the above trends in designing materials, particularly hybrid materials, will be paralleled by trends in manufacturing fine scale materials (at the scale of individual atoms) and thin layer structures. Chemical synthesis methods such as sol-gel processing will be used, as will methods for controlling process energy precisely, such as laser processing. As nanoscale devices become available for sensors and actuators in hybrid materials, smart materials will be synthesised at a molecular level through application of principles such as self-assembly and molecular recognition. These principles have been studied in biological systems.

The principles that relate the functions of biomolecules and tissue structural components to their molecular structure are now well enough understood to be used in designing materials. Among the potential applications are new battle gear for the soldier made from lighter and stronger fabrics, broad spectrum vaccines and prophylactic medicines, sensors and diagnostic devices based on molecular recognition properties, and miniature motors and power supplies based on biological energy transduction mechanisms.

New materials are characterised by their new or improved structural qualities, which are often tailored to highly specific applications. The trend is shifting from the multipurpose materials to materials with specific characterisations such as

- Metals - Lightweight, high temperature, magnetic materials
- Ceramics - Maximum resistance to temperature and wear, ceramic high temperature super conductors
- Polymers - Electrical and optical characteristics, high temperature resistance
- Intelligent - Sensor and information processing components (e.g. smart skins)
- structures and
- materials

Availability:
Estimate of technology maturity for full-scale system engineering development:

The development of new materials is an ongoing process which will be able to provide tailored to need materials as follows:

- extreme high temperature resistant, inter-metallic compounds used for machine components (e.g. in aircraft engines or turbines), 2005
- heat resistant plastic material with a temperature resistance of more than 450 degrees C in continuous operation, 2005
- integrated circuits resisting temperatures of over 500 degrees C 2005
- high polymer materials with comparable electrical properties to copper under environmental temperatures, 2010
- intelligent materials with sensory, effectory and storage properties, 2005
- Materials which permit the control of the structures and properties of solid component interfaces on the atomic level 2005
- Organic hybrid materials and 2010
- interfacially determined materials with predetermined properties. 2010

Impact on military ground force capability:

The new materials permit improvements on a large scale. Their application ranges from soldier clothing to vehicle and aircraft construction, electronics and signature reduction of weapon systems as well as an overall performance improvement. Some future developments include:

- The design of highly effective laser protective goggles that still allow unrestricted vision.
- The design so-called smart skins, which, depending on certain external influences, change their shape (e.g. change of wing or rotor geometry depending on incident flow).
- Intrinsic conducting plastics that will enable a low cost manufacture of electrically conducting layers, increasing processor and electronics power at reduced weight and size.
- Nano-crystalline-coated materials will be designed, with application toward increasing the wear resistance of gun tubes.
- Penetrators consisting of extremely fine-grained materials will be developed having maximum ductility giving better performance against advanced armours.
- Protective electromagnetic armours will be developed that will have increased effectiveness at reduced weight, etc.
- The development of advanced manufacturing processes for ceramic armour will provide the military with lighter, cheaper and more efficient passive armour systems.

Evolutionary improvements in materials technology will provide lower weight munitions components and submunitions, and reduced weight aircraft armour and structure with the same or better performance. Human performance enhancement through lighter weight components and effective ballistic protection will be realised.

Logistics improvements due to improved battlefield energy management; storage and portability are also possible.

With a view to the 2020 battlefield specific development improvements are possible and in the following advanced materials technologies are possible and imperative at the same time:

4.8.1 ***Low Observable Materials***

- Low observable materials are to be defined as "Materials that when applied to a platform will reduce the signature and so enhance the ability of that platform to avoid being detected and tracked and thereby increase the survivability of the platform".
- The range of signatures addressed include visual (Mark 1 eyeball), near IR (Image intensifiers), IR (3-5μm hot spot thermal imaging and 8-12μm target recognition), and radar (cm frequencies - fire and control systems and mm frequencies - missile seekers).

- Such materials could be applicable to all military vehicles, static emplacements, bridging, UGV's and helicopters. There are four generic categories of materials that are applicable to land based platforms:
- Composites
  - Structural Radar Absorbent Materials (RAM), pigmented and with Frequency Selecting Surfaces (FSS) skin
  - AFV hulls, Logistic vehicles, Air defence, static installations
- Ceramics
  - Radar absorbing treatments, FSS surfaces
  - Armour
- Elastomers
  - Radar absorbing treatments, pigmented
- Paints and coatings
  - Radar absorbing treatments, IR emissivity controlled, pigmented
- There are particular problems that need to be addressed now concerned with thermal management, but there is still interest in the other signatures for future platforms. One issue is the management of solar load effects which is especially important for non-metals.

<u>Evolutionary performance gains expected from the current research programmes</u>

- The current research programmes are directed at evolving the current state of the art materials and structures. Within these programmes there is a large amount of synergy between the different environments, land, sea and air. Currently the bulk of the funding lies in the air and sea applied research packages, with a smaller level of funding within the CRP directed at tri-service applications.
- These programmes will deliver the Basic Technology that would be available in 2020. This is expected to consist of broad band radar signature reduction, whereby the current narrow and medium width capability will be expanded to cover a significantly wider threat bands. Materials with controlled emissivity in both IR bands. These materials should be designed to enable significant differences in emissivity to be produced in the two IR threat bands if required.
- Controlled visual signatures, whereby the visual signature of the platform can be designed for the desired environment without detriment to other signatures. Increasingly there will be demand for simple additional capabilities to be built into the structures, which the latest materials will be able to accommodate. These low signature structures will be able to be made with no weight penalty over non stealthy structures using conventional materials. A driver is to provide these low signature benefits at minimum increased cost

Possible revolutionary performance gains that may be available 2020 and beyond

- The Advanced Technology potentially available in 2020 could consist of multi-spectral materials that can cover all threat bands including visual, near IR, and radar in a single material system. This would involve tailoring the properties of the individual materials to give the desired signature performance for the particular threat band without detriment to the other bands. It is likely that the material system will be a combination of a range of materials.
- Dynamic signature control, which will enable a weapons system to adapt it's signature interactively in response to changes in the environment. For example when moving between different backgrounds or to generate a false signature. The ability to build further additional capabilities into the structure, such as health monitoring, without detriment to the system signature. The ground work for these technologies is beginning today, but is currently directed at the sea and air environment

Examples of revolutionary new system/platform concepts:

- The low observable materials technology is applicable to all system/platform concepts, but to gain greatest benefit from these technologies they must be designed in from the start, even at the concept stage.
- Anywhere where increased survivability is required will benefit from LO materials technology.
- Examples of new systems that would are ultra low signature reconnaissance vehicles, support installations, such as mobile HQs and bridges, and the future MBT.

4.8.2 *Steels Technology*

- Steels are of primary importance for the survivability of Heavy Armoured Fighting Vehicles (AFV) and the firepower improvement in Light AFVs, Artillery, Air defence and Infantry applications.
- Steels are of secondary importance for mobility in Heavy AFVs and for life cycle cost reduction in Light AFVs, Artillery, Air defence and infantry.
- Considering Heavy AFVs, the survivability can be increased by the use of materials with high strength (high flow stress), high density, increased strain rate and high degree of strain rate hardening. Mobility of Heavy AFVs can be increased by the use of materials with high mass efficiency and high space efficiency
- Proposed methods of improving performance in mobility and survivability are:
  - micro alloying
  - use of cleaner steels
  - use of Si modified steel

  - powder metallurgy route
  - steel based MMCs
  - tool steels.

- Firepower can be increased by;
  - the use of high strength and high toughness steels to withstand increased pressures so that higher muzzle velocity and range are obtained.
- Lower Life cycle costs can be obtained by;
  - use of new family of wear and erosion resistant steels to achieve higher rates of fire.
  - functionally graded steel (e.g. Osprey process)
  - changes in rifling geometry to make the barrels electro-plating friendly.
- Other ideas:
  - Improved RHA
  - Steel Metal Matrix Composites (MMC)
  - High pressure and in particular high wear and erosion resistant gun-tubes
  - Need to look at electro thermal gun characteristics
  - Rifling geometry, electro plating friendly (60 degree), retrial needed?
  - Stelite liners for gun-tubes
  - Liners, ceramic? (hoop stress thermal shock)
  - 'J' steel Def Stan 1013
  - Plasma arc melting process
  - Osprey process
  - Functionally graded, fragment design
  - Bainitic steels
  - Tool steels M42, D6
  - Ti barrel sheath
  - Potential life extension great benefit
  - Injection moulding steel polymer binders

<u>Evolutionary performance gains expected from the current research programmes</u>

- An increase in survivability of heavy AFVs by the development of armour steels that have a high degree of strain hardening compared with conventional armour steels. The strain hardening is important because its occurrence is thought to suppress adiabatic shear (a low energy fracture mechanism which is characteristic of armour steels).

- Reduction in the life cycle costs of gun barrels (in heavy AFVs, artillery etc.) by the development of high strength, high toughness steels with high wear resistance, especially with a view to new high performance tank guns. At present, the requirement of steel is to give adequate strength and toughness but not high wear and erosion resistance

Possible revolutionary performance gains that may be available 2020 and beyond

- Possible armour material produced by powder metallurgy related processing with total resistance to KE penetrators.
- Possible high strength steels for barrels with total wear and erosion resistance that does not need extra protective coatings.
- Possible forming methods to produce plates of armour and/or gun barrels without the various steps of conventional processing and machining.

Examples of revolutionary new system/platform concepts:

- Heavy AFVs with blocks of armour plates easily produced by powder metallurgy route so that these blocks can be easily replaced.
- Heavy AFVs made of steel composites that would have a mechanism to divert the path of the penetrators.
- Small calibre barrels produced to near net shape by powder metallurgy process minimising the processing and machining costs
- Powder metallurgy:
  - High hardness steels could be produced by this powder metallurgy method, but this technology is only likely to result in small incremental changes in protection level. Production method could reduce cost vs. tool steels and therefore allow them to be used in more applications.
  - Laminated use of powdering in tougher steels. Could combine ceramic with steel to produce a functionally graded material to optimise performance and weight.
  - Wear resistance for track links and pins. Gun tubes with greater life through better wear resistance.
  - Self-lubricated steels for pins, bearings etc avoidance of rubber bushes.
  - Controlled/non magnetic steels for reduced signature.
  - Micro voided steel, high strength/stiffness to weight ratio.
  - Closed cell Aero bar material, reduce behind armour effects and blast absorption.

4.8.3 ***Titanium alloys and MMCs***

- Titanium alloys are already used extensively in aircraft, aeroengines and missiles
- Current research programmes are aimed at:
  - mechanical property/density improvements through new alloy processing routes, such as mechanical alloying and vapour deposition. For example, a new titanium/magnesium alloy has been developed with a density up to 30% lower than conventional titanium alloy.

- cost reduction through the development of new near-net-shape processing routes, intended to improve material utilisation during manufacturing and fabrication. For example, a joint industry programme on close-to-form forging is aimed principally at titanium applications in aircraft landing gear, and in lightweight air-portable ordnance. Another joint industry programme on titanium metal matrix composites will develop cost effective manufacturing routes for complex component shapes, such as reinforced titanium rings and aeroengine blades.

- Titanium is 40% lighter than steel, more corrosion resistant than stainless steel, strong and tough, but expensive. Titanium would be very attractive as a lightweight replacement for steel in a wide range of military equipment, but the current high cost limits its use.

- Future research will be directed to reducing the cost of titanium alloys for land based military applications, and the following options are under consideration:

- Pure titanium sponge - currently extracted from the ore in a very expensive batch process, which is not suitable for continuous production. Several alternatives may be possible, including, for example, electrolytic refining, or vapour phase reaction.

- Alloys - substitute lower cost alloying additions, such as iron or oxygen.

- Alloy melting - currently electric arc batch process. Cost reduction would be possible through continuous casting (as has been done in the steel industry), and alternative-melting methods, such as electron beam or plasma may bring cost benefits.

- Relax aerospace specifications to reduce melting costs for land based uses.

- Non-melting alloy productions route - it may be possible to process sponge directly into alloy ingots using powder blending and solid state sintering.

<u>Evolutionary performance gains expected from the current research programmes</u>

- Current research on new high performance titanium alloys and composites should provide materials for critical applications. In particular, work on titanium metal matrix composites will be applied to the development of the next generation of military jet engines. It is projected that a fibre reinforced titanium alloy bladed ring (BLING) will save up to 70% weight compared with the conventional disc and blade assembly. This will facilitate novel aeroengine designs, and will lead to increased aircraft performance/ reduced fuel consumption and reduced lifetime costs.

- The application of close-to-form forging technology to titanium alloys will greatly improve the material utilisation for applications such as aircraft landing gear. For example, current forged and machined steel landing gear parts use only 10% of the initial weight of the forging. Clearly this I wastage is not acceptable for the more expensive titanium alloy.

Possible revolutionary performance gains that may be available 2020 and beyond

- Work planned on reducing the cost of titanium alloys will make titanium available for use in a range of light-weight air-portable equipment, including howitzer ordnance and armoured vehicles of all types. Titanium has similar ballistic performance to steel of the same thickness and is 40% lighter. It is attractive as a same-weight upgrade where the threat has increased, or for future lightweight air-portable vehicles. Compared on a weight basis, titanium has superior ballistic performance to both steel and aluminium, and is much less bulky than aluminium. Other advantages are that titanium is non-magnetic, and is totally immune to corrosion.
- Titanium could be used to fulfill known requirements to reduce substantially the weight of AFVs. Possible applications on vehicles are: hatches, engine decking, skirts, appliqué armour and hull structure. For aircraft, the armour requirements are for pilot protection in close ground support aircraft and for lower fuselage protection in transport aircraft on peacekeeping and evacuation missions.

Examples of revolutionary new system/platform concepts:

- Vehicles that float/swim.
- Shape memory materials used as actuators. Applications: self-erecting buildings; POW camps; antenna; signature control through shape change.
- Armour materials, good absorber.
- Naturally low magnetic signature, good blast protection, could be used in mine crossing applications.
- Increase bridge span crossing.
- Titanium MMC for gun barrel over raps.
- Muzzle breaks

4.8.4 ***Unconventional alloys***

- Tungsten heavy alloys (WHA)
- DU
- Magnesium
- Nickel

- Hydrogen storage
- Magentics
- Shape charge liners
- Complex targets a challenge
- Fibrous tungsten WHA
- Functionally graded, for penetrators
- Terminal effects of WHA not fully understood. Difficult manufacturing process
- Fibre reinforcing
- Particulate reinforcement
- Tungsten fibre MMCs
- Glassy metals
- Surface coatings, track wear
- Understanding 'integration' is the way forward not new materials

Evolutionary performance gains expected from the current research programmes

- Improved performance of copper, moly, DU, tantalum shape charge liners, through control of micro structure

Possible revolutionary performance gains that may be available 2020 and beyond

- Storage of hydrogen for fuel cells in nano carbon tubular structures
- Tungsten: DU performance from tungsten in a KE penetrator
- Magnesium: enerfoil initiators munitions, pyrotechnics, gas generators

Examples of revolutionary new system/platform concepts:

- Hybrid powered vehicles
- Fuel source for miniature power supplies

4.8.5 ***Polymers***

- Low density (1-2g/cc) beneficial to:
  - increased mobility for man-portable equipment such as LAWs, infantry weapons,
  - e.g. rifles, close support weapons (as structures and furniture)
  - lightweight missile components for increased speed and agility
  - Packaging
  - Mass production offers low unit cost combined with the ability to fabricate complex components to near net shape, integrated assembly techniques, no finishing/painting and with low/no maintenance

  - Build in additional functionality
  - Energy absorbing, e.g. for protective layers (stealthy or heat resistant) for defence of missiles against Defensive Aid Suites (DAS)
  - Adhesively jointed armours, no edge effects
  - Lightweight sabots for small to medium calibre kinetic energy ammunition may offer the potential for increased lethality at an affordable cost by reducing parasitic mass
  - Polymeric damping, e.g. for improved gun barrel dynamics using a polymeric damping system to reduce tip excursions between rounds
  - Mine cases, explosive ordnance and demolition equipment
  - Man portable equipment such as LAWs, infantry weapons, rifles, close support weapons (as structures and furniture)
  - Gap crossing using easily deployable lightweight foams or tubes
- Shape charge liners with novel performance characteristics:
  - Long jets - for attack of hardened targets, bunkers, top attack of vehicles (possible in tandem warhead concepts) and shock fracture
  - Profiled liners for achieving special effects
  - Pyrophoric effect by the incorporation of additives
  - Defeat electric armours
  - Defeat Explosive Reactive Armour (ERA)
- Non lethal weapons, such as:
  - Adhesives to disrupt the mobility and operation of enemy forces and equipment
  - Carbon fibres to immobilise electrical and electronic equipment
  - Dissolving/cracking agents, to damage, destroy or otherwise render inoperative the plastic components of enemy equipment (e.g. rifles, sights)

<u>Evolutionary performance gains expected from the current research programmes</u>

- Vibration mounts capable of improving life of vehicle mounted equipment
- Track bushes, pads for increased availability of AFVs
- Fuel pipe lines with increased toughness for improved vehicle survivability
- Fuel and water tanks with increased toughness for improved vehicle survivability
- Sealants
- Rubber like materials with low hysteresis would be very beneficial to reducing the thermal signature of wheels and track pads/bushes.

Possible revolutionary performance gains that may be available 2020 and beyond

- Adhesive bonding, self-repairing adhesives, self sensing joints.
- Energy absorbing adhesive joints for improved survivability (e.g. AFVs, missiles for Counter Defensive Aid Suits (CDAS)
- Improve high temperature performance, toughness
- Wet condition bonding (for repairs and engineering construction under battlefield conditions)
- Next generation high-performance structural polymer fibres (e.g. next generation aramid and high density polythene fibres) for more weight efficient applications and structures (e.g. body/vehicle armour, lightweight sabots, missile structures, launch tubes
- Geo textiles and membranes for road/route preparation - more rapid and deeper penetration
- Soil/sand stabilisation

Examples of revolutionary new system/platform concepts:

- Battle damage repair
- Fuel storage
- Modular structures, bonded in the field
- Structural foams, gap crossing
- Non lethal warfare, glues, slippery agents
- Body armour

4.8.6 ***Novel Energetic Materials***

Novel energetic materials are used in explosives and propellants. The last 80 years history in conventional energetic materials has only produced small increases (<20% better than TNT) in energy density.

Evolutionary performance gains expected from the current research programmes

Evolutionary performance gains expected from the current research programmes suggest up to 30% (nanostructural aluminium) better performance than TNT. This would probably first result in rockets with better performances. Later this could lead to more efficient ammunition.

Possible revolutionary performance gains that may be available 2020 and beyond

Revolutionary performance gains have been demonstrated in theory at this time. This would suggest up to 3000% (metallic hydrogen) better performance than TNT. When achieved, this would require development of new materials and new technology for warheads to be explored.

Examples of revolutionary new system/platform concepts:

The consequences includes more efficient shaped charges (up to 40% higher penetration capabilities), more efficient blast shells (2-5 times more efficient) and probably lighter missiles, which could have significant impact on the capacity of combat helicopters.

4.9 TECHNOLOGY AREA – MAN-MACHINE-INTERFACE

Introduction:

The technological advances in almost every field, particularly in computer aided processes, requires new forms of co-operation between man and machine. The investigation of this man-machine interface is designed to reduce the cognitive, physical and emotional strain on the human being in order to enhance the effectiveness of the man-machine co-operation. The importance of this interface investigation is underlined by the fact that the so-called human error - which today is often cited when no hardware error can be found - could be minimised by improving the man-machine interface. From the present point of view, the interface between man and machine can be regarded as an impeding factor.

Although there remains the necessity for the development of MMI technologies for special military applications, the developments of the civil sector will have strong synergistic effects.

It is also recognised that the Army of the future will be vastly different in terms of an individual's role, the organisational structure and the mission objectives. This will be either due to technological advances or changes in worldwide political influences. Such a change in job requirements will create need for changes in training and recruitment, perhaps in terms of leadership, decision making, information processing, team interaction in addition to the changes in technical tasks. Advances in psychology research will be manifested in tools and techniques for addressing such changes.

4.9.1 ***Human Machine Interfaces***

Description:

This technology allows the humans in the loop to exploit all information relevant to their individual tasks, without reaching "information overload" and respond in a timely manner. The approach is to make maximum effective use of all the human senses and intellect to perform this task in as natural appearing an environment as possible. One technical challenge is to build and incorporate affordable, high-resolution large 3-D displays into systems to depict an accurate picture of the situation to the visual senses and enhance those system interfaces with natural language and gesture input/output. A second technical challenge is to provide a truly interactive, virtual reality depiction of the situation with human "immersion." The depiction will ultimately be further enhanced by removing artificial tethers such as helmet mounted displays and data gloves, providing real-time updates to the depiction, and allowing the immersion of multiple humans at the same time. Some aids to visualisation (especially in head up displays) rely on sensing the location and orientation of the participant. Participant location and orientation are

used to adjust the presented visual scene. A third challenge is improvements in measurement resolution, accuracy, and responsiveness needed to promote improvements in aids to visualisation.

Relationship with Computer Technology Area:

Information presentation and interaction with military computer systems require advancements to achieve the goals for optimising human performance in the information rich combat environments of the future.

These include:

- real-time adaptable user interfaces,
- crew-aiding systems,
- intuitive multi-user interfaces,
- real-time processing and display of solid objects,
- locomotion control,
- robust real-time speech recognition and understanding,
- text processing, understanding, and multi-lingual translation, and
- interface and interaction development tools to facilitate design and development of interfaces, human-computer dialogs, integration of human and computer control, system composition and integration, and virtual reality fidelity.
- decision support aids.
- wargaming tools.
- information management tools.

Availability:

Estimate of technology maturity for full-scale system engineering development:

- Processing of vague information in a common sense language 2005
- Computer networks are able to create a true "virtual reality" 2010
- Physiological and psychological factors on which human errors are based will be understood 2010
- Sensors will be developed which can be coupled to the sensoric nervous system 2010
- Interface between the sensory organs and computers developed 2010

Impact on military ground force capability:

Integration of advanced human machine interface technology will provide efficient and survivable combat and combat support systems. These will enhance situational awareness, reduce training overhead, reduce workload, improve

teamwork. Applications include virtual heads up displays for vehicle commanders, interactive situational awareness displays, intelligent decision support systems with virtual displays and optimised controls for autonomous systems

A possible development could be the control of instructions and procedures by the sensory organs (e.g. eye movements) which will be processed by computer systems and transmitted to the addressee (e.g. actuators, contact person). These technologies could have critical application to the soldier system.

In the development of command, reconnaissance and weapons systems the level of automation continually rises. To make optimum use of these systems, better adjusted interfaces must be developed, which are based on the knowledge of human behaviour, on man's general capability and on his interaction with the system (e.g. heads up display/hands off display).

4.9.2 ***Human Systems Optimisation***

<u>Description</u>

Over the last 10 years, significant advances in psychology research has enhanced our understanding of human decision making, team interaction processes, individual differences (e.g. the role of expertise), workload capacity etc. Furthermore, techniques for eliciting user requirements, designing systems and evaluating technology have become increasingly formalised and effective.

It is anticipated that over the next 10 years, further advances will provide solid techniques for enhancing cognitive and social performance through training. Also, cognitive knowledge elicitation techniques will be more widespread for capturing requirements for technology systems and associated training. Synthetic Environments will be more realistic and provide an environment for training, system evaluation and requirements capture.

<u>Relationship with computer technology area</u>

The only techniques dependant upon technology advances is training, evaluation and requirements capture within SE's (this is described in section 3.4 of this annex).

<u>Availability</u>

Time scales are dependent on level of validity.

Training in ad-hoc and distributed team interaction 2005

Training in pitfall technology issues 2005

Standardised techniques for cognitive knowledge elicitation 2005

Realistic immersive and configurable SEs for training, evaluation or requirements capture 2015

Tools and techniques for evaluating fidelity of SEs 2010

Impact on military ground force effectiveness

Training will be used to improve creative decision making, team interaction, understanding of technology issues (e.g. overconfidence, cognitive 'loafing', information processing and management techniques) etc., which will be important for battlefield commanders, HQ planning teams and even the soldier on the ground.

Improved techniques for identifying requirements, designing usable systems and evaluating human-dependant systems will lead to the development of effective technologies that support specific military needs. This will also reduce money spent on developing technology with no operational benefit.

4.10 TECHNOLOGY AREA – PRECISION ATTACK WEAPONS

4.10.1 Precision Attack Weapons

Introduction:

Precision Attack is more a philosophy of war than it is a single technology and this paper will inevitably only describe a small part of it. It is usually taken to mean attack of high value ground targets at ranges beyond line of sight in circumstances where it is essential to have a very high probability of hit and a correspondingly low risk of collateral damage. However the term could equally well be applied to direct fire, tank versus tank engagements, and to air defence operations where it is essential to kill incoming aircraft and missiles. In fact much of the seeker and guidance technology used for Precision Attack was developed initially for air defence applications.

In the system of systems that is Precision Attack there are four essential elements:

- Reconnaissance, Intelligence, Surveillance and Target Acquisition (RISTA) assets which detect, identify and precisely locate appropriate targets, often at ranges of over 100km. Intelligence (HUMINT) data are essential for identifying targets that comprise, for example, particular floors within a building, or the precise composition of a hardened bunker's walls.
- A weapon system capable of delivering the required warhead to the target in a controllable way.
- A system for speedily assessing post attack damage, which may either use the original RISTA assets or separate ones designed specifically for this purpose.
- A flexible Command and Control system that can speedily process the target information, facilitate the command decisions which in some cases will have a political dimension, and issue timely orders to the weapon commander. Latency of information is one of the greatest problems for Precision Attack. In cases where targets are moving, such as mobile missile launchers, or divisions of tanks, it may be necessary to have an automatic or semi automatic system of "sensor to shooter" information flow that incorporates the

appropriate Rules of Engagement. This is likely to have significant doctrinal implications.

4.10.1.1 Precision Attack Technologies

Description:

A continuing technological trend will be the application of precision attack technologies to ground warfare. One technological innovation will be the application of multi-spectral seekers for ground to air missiles. This precision attack technology will be fully autonomous and Command to Line of Sight (CLOS) will not be required. Technology will be more robust to countermeasures and provide an all-weather capability. Multi-service commonality is desirable and achievable.

Smart and brilliant munitions will continue to be developed for ground to ground applications in the future. An example of a maturing precision attack technology is fibre optic guided weapons. These weapons will allow the destruction of high value assets with minimum collateral damage. Advances in digital communications architectures, sensors and processor technology will result in the ability to select one target out of many even in a cluttered background.

Intelligent artillery munitions with increased terminal effectiveness will result in reduced ammunition and logistic supply requirements. Better sensors and processing capability will provide better control of the sensor footprint and allow the capability to engage high value targets at longer ranges.

Availability:

Estimate of technology maturity for full-scale system engineering development: 2010 - 2020

Impact on military ground force capability:

- Multi-spectral seekers will provide enhanced ground/ship air defence, particularly integrated "force" defence, greater flexibility, greater range, and a rapid launch rate all of which will enhance force protection and individual survivability.
- Fibre optic guided weapons allow precision attack of high value targets with minimum collateral damage. Improved sensor packages and situational awareness resulting from enhanced sensor to shooter architectures will provide confirmation of target destruction and battle damage assessment. The standoff capability will have a profound impact on not only lethality but also survivability.
- Intelligent artillery munitions will have improved control of sensor footprints allowing better search and acquisition routines. Munitions integrated with Global Positioning System (GPS) and with some manoeuvre capability will reduce errors by at least an order of magnitude. This will provide increased range, significantly reduced collateral damage and reduced ammunition and logistic burden.

4.10.2 Systems

This section will concentrate on the weapon systems necessary for Precision Attack. For the most part these are either in service now or are being actively researched, so that one can be reasonably sure that they could be available by 2020. Next, the underpinning technologies necessary for these systems will be identified. It turns out that for the most part these technologies are already relatively mature, so they will not be described in detail. Finally some key issues will be identified.

4.10.2.1 Bomblets

Description:

Bomblets may be artillery, air or missile borne. Instead of a single (explosive) shell or warhead many bomblets will be dispensed within an overall footprint. Precision is achieved by virtue of the fact that there is a greater probability of hitting a target within the overall footprint by many small warheads than by a single one. In terms of overall effectiveness, there is a trade-off between number and size of munitions.

Availability:

Estimate of technology maturity for full-scale system engineering development:

- Bomblet munitions are already in service.

Impact on military ground force capability:

Although bomblets are hardly precision weapons in the sense of this paper, they do provide a means of attacking armoured vehicles, either singly or in formation.

4.10.2.2 Intelligent artillery

Description:

Intelligent Artillery means course corrected munitions. At long ranges, errors in range, attributable to small errors in muzzle velocity are greatly magnified. The concept of course corrected munitions is for onboard sensors to either measure the muzzle velocity or compare the actual trajectory with the desired one and retard the shell by means of canards or other aerodynamic surfaces so that it falls closer to target.

Availability:

Estimate of technology maturity for full-scale system engineering development:

Course corrected munitions are currently being researched and could enter service by 2010 - 2020

Impact on military ground force capability:

It is unlikely that course corrected munitions will ever achieve the sort of pinpoint accuracy that is required for the most sensitive of targets. Nonetheless, using

course corrected munitions as part of a precision attack system will reduce the targeting problem and increase the precision of, for example, bomblets, sensor fused munitions or terminally guided sub-munitions, which may be artillery borne.

4.10.2.3 Sensor fused munitions

Description:
Sensor fused munitions may be artillery or missile borne. They descend by parachute and have sensors (mm or IR) which scan out a spiral path on the ground. When the sensor detects a target in its field of view, the warhead fires. Stand-off ranges may be of order 100m.

Availability:
Estimate of technology maturity for full-scale system engineering development:

US already has a prototype system called SADDARM, so systems of this sort could easily be in service by 2010 - 2020

Impact on military ground force capability:
The obvious application for SFM is the attack of mobile targets such as MBTs or missile launchers, relying on the rapid time of flight for artillery launched systems.

4.10.2.4 Terminally Guided Sub-Munitions

Description:
Terminally guided sub-munitions tend to be delivered by missile systems rather than guns because of their size: typically a 155mm shell could deliver 1, while a rocket, such as MLRS could carry 3-6. TGSMs use mm seekers and aerodynamic control in the same way as conventional air defence missile systems. Tandem warheads are the norm to defeat reactive armours.

Availability:
Estimate of technology maturity for full-scale system engineering development:
Present day to 2010

Impact on military ground force capability:
TGSM are principally intended for the defeat of tanks, missile launchers and other mobile targets.

4.10.2.5 Anti-Tank Guided Weapons

Description:
Anti Tank Guided Weapons are already in service. Typically they are a shoulder launched infantry weapon using a short length of fibre optic cable to receive guidance (command to line of sight) from the ground station to which they are attached and from which the operator keeps his sight trained on the target in order to ensure that the missile overflies the target. In the vicinity of the target, the on board sensor (typically IR) detects the vehicle sides and detonates the (tandem) warhead as the missile flies over the top.

Availability:

Estimate of technology maturity for full-scale system engineering development:
Present to 2005

Impact on military ground force capability:

For the top attack of tanks and other armoured fighting vehicles, using the fact that armour protection there is always significantly less than on the front.

4.10.2.6 Fibre Optic Guided Munitions

Description:

Fibre optic Guided munitions are similar in concept to ATGW, but are larger and have much greater range, typically 20-100 km. The missiles are guided by a combination of GPS and INS, via a network of waypoints to the target. On board IR or visible sensors transmit imagery en-route, which is not only a valuable source of intelligence information but also allows the human operator to confirm final target identification prior to attack. Transmitting raw imagery data via the fibre optic to the ground station where it is processed is much cheaper than carrying on-board processing, and the man-in-the-loop final control facilitates the reduction of collateral damage. FOG(M)s could in principle be flown entirely by remote control, but the operator workload would be very high.

Availability:

Estimate of technology maturity for full-scale system engineering development:

Prototype FOG(M)s are already available and a French example is claimed to have 100km range. Such systems could easily be in widespread service by 2010

Impact on military ground force capability:

FOG(M)s could be used equally well for the attack f fixed or moving targets. However flight times will be significantly longer than from artillery borne systems. Because of their expense, FOG(M)s are more likely to be used against higher value targets, such as Command and Control centres, rather than individual armoured vehicles.

4.10.2.7 Cruise Missiles

Description:

Cruise missiles are a well-known technology. They are capable of delivering a nuclear warhead accurately over very long ranges, using a combination of terrain matching and inertial navigation. They were used to good effect against fixed targets in the Gulf War, equipped with conventional warheads. The need to avoid detection over the long duration of a cruise missile's flight forces it to fly low, for which terrain referenced navigation is essential. In turn this requires accurate mapping data for targets which in some cases is difficult and time consuming to obtain. Altogether, Cruise Missiles are extremely expensive.

Availability:
Estimate of technology maturity for full-scale system engineering development:

In service at present. Cheaper versions of cruise missiles could be made using GPS navigation, mimicking the World War II V1 weapon. These could easily be in service by 2020

Impact on military ground force capability:
The size and cost and navigation systems of cruise weapons means that they are only really suitable for the direct attack of very high value assets, such as command and control bunkers, or other fixed plants.

4.10.2.8 Laser guided bombs/DMP

Description:
Laser guided bombs (e.g. the 1000 lbs. PAVEWAY) are dropped from fixed wing aircraft and guide themselves onto target by means or aerodynamic surfaces using a laser designator operated from a separate aircraft. Typical accuracies are of order 10m. Dense Metal Penetrators are scaled up versions of long rod penetrators that are designed to penetrate through the complex walls of hardened bunkers before detonating on the inside. They are also laser guided. Current systems require manned designators but in the future it is conceivable that automatic laser designators could be mounted on UAVs; indeed UAVs could also be used to deliver the bomb, reducing the system cost considerably.

Availability:
Estimate of technology maturity for full-scale system engineering development:

Present day to 2010

Impact on military ground force capability:
These systems are primarily designed for defeating hardened fixed installations.

4.10.2.9 Intelligent fuzing

Description:
The idea of an intelligent fuse is linked to the need for defeating hardened bunkers. These structures tend to have complex walls comprising alternate layers of hard and soft materials that are designed to spoof dumb fuses into detonating the warhead before it has penetrated into the interior. Intelligent fuses use accelerometer technology to detect the resistance that a weapon is experiencing during penetration. The key problem is ensuring that the fuse can survive the extreme decelerations that occur.

Availability:
Estimate of technology maturity for full-scale system engineering development:
Available by 2020

Impact on military ground force capability:

A system solely designed for the attack of bunkers. The concept of intelligent fuzing can also be applied to other scenarios, for example in air defence. Here onboard intelligence analyses seeker data, predicts the time of closest approach to the target and detonates the warhead then.

4.10.3 ***Underpinning Technologies***

A large number of underpinning technologies are required for precision attack weapons. Guided by the LO2020 technology taxonomy, the key ones may be subdivided and categorised as follows:

intelligence analyses seeker data, predicts the time of closest approach to the target and detonates the warhead then.

Delivery subsystem:

- Artillery
- Missile
  - Rocket motors (e.g. ATGW)
  - Air breathing (e.g. Cruise)
  - UAV

Navigation:

- Inertial navigation systems
- Terrain Referenced systems
- Satellite Navigation (GPS)
- Control to line of sight
  - Visible/IR
  - Radar Information Field
  - Laser designators

Flight control: .

- Canards
- Fins
- Vectored thrust

Sensors/seekers/fuzes:

- visible
- mm
- IR
- Multi-spectral
- Accelerometer

Warhead:

- Shape charge
  - Jets
  - Explosively formed projectiles
- High Explosive
- Dense Metal Penetrators

Lower level underpinning technologies

This exercise could readily be continued to lower levels, which would reveal the role of computing technologies, of electronic devices and of novel materials. In fact a full decomposition down to fundamental technologies would comprise a very long list indeed, and this would be even longer if the RISTA and C3I aspects of a full precision attack system were also to be included.

The future: Evolution or Revolution?

The dramatic Gulf War images of precision attack against buildings and bridges shows that the revolutionary impact of such systems is already here in so far as the technologies are concerned. Evolutionary changes are thus what we must expect for the battlefield of 2020. Active research programmes are currently under way in all of the underlying technologies listed above and each may be expected to improve significantly. Two important conclusions follow from this:

Need for upgradeability

Future systems will always use out of date technology unless provision is made in the design that will facilitate upgrades, in particular of processing power. This must not be the same as specification creep and it needs to be planned for from the start of a procurement exercise.

Importance of system integration

Given the sheer complexity of precision attack weapons, and the relative maturity of all the underpinning technologies, it is clear that systems integration is the key to major improvements in performance. This conclusion is further amplified considering the way in which precision attack systems require to be integrated into the Command and Control systems of future (digitised) battlefields. Maximum effectiveness against moving targets is likely to demand an automated sensor to shooter link from widely separated parts of the battlefield.

A cautionary psychological footnote

Precision attack is firmly established as part of modern military thinking and it appears to offer compelling advantages. However to win wars it is necessary to shatter an enemies morale, and it is far from clear that precision attack achieves this as readily as it shatters his buildings. An example from history illustrates this:

In WWII, the Japanese devised the system of Kamikaze pilots in order to deliver precise attack on allied naval ships and believed that willing self-sacrifice of the pilots would be a powerful, additional and decisive psychological weapon.

However the evidence shows that such attacks were not significantly more effective than conventional attacks, either psychologically or physically. We must therefore avoid overselling precision attack: It will be vitally important, but only one part of an overall offensive capability.

4.11 TECHNOLOGY AREA – ROBOTICS AND AUTOMATION

Introduction:

Planning for the future military capabilities assumes the availability of highly mobile, agile, rapidly deployable forces. Incorporation of robotic and semi robotic systems into future force structure to reduce casualties, increase tactical reach, counter battle fatigue and reduce logistic burdens for rapid reaction forces offers one potential pathway for achieving this goal.

Even though not being a technology by itself robotics and automation will play an increasing role on the battlefield. Robots will act as force multipliers on the future battlefield, augmenting humans in many high-risk missions. They will expand military units' capabilities by increasing situational awareness, providing tactical remote fires on demand, and reducing logistics burdens through reductions in combat vehicle size. Expanded machine intelligence will enable new modes of soldier-robot interactions reducing the heavy burden placed on the future soldier by allowing the soldiers to supervise (rather than directly control) multiple robot systems, each with a substantial level of autonomy. Information will be filtered, providing the operator only essential details and alerts and automating systems that can implement "just in time" delivery techniques on the battlefield.

Near term major improvements in sensors, sensor size and weight, small size computers, computational power of microprocessors, micromechanics, man machine interfaces including communication technology will make feasible the use of robots in many applications for future special forces operations.

In the area of automotion robotics have already been studied to great extent. Nondriver vehicles, equipped with sensors and computing devices necessary to navigate in unknown terrain, have already been demonstrated. Still it will be a long way ahead until robot vehicles will be able to autonomously operate on the battlefield following a given command. Semi robotic, remotely controlled systems, however, are not far from realisation such as intelligent weapon systems programmed to approach its targets on a designated path on the ground and in air including the ability to communicate with an operator for target acquisition are close to fielding. UAV's and drones have to be considered within this same category of systems.

With the continuous increase in capability of processing and sensor technologies and cost reduction it will soon become feasible to replace the soldier in many dangerous mission areas and to improve automated surveillance, sentry, monitoring functions, mine detection and clearing as well as to operate in active B&C environments.

4.11.1 Intelligent Machines: Unmanned Ground Vehicles

Description:

Realisation of the land force leap ahead unmanned ground vehicles can provide requires a concerted technology thrust in a number of areas. Chief among these is the sensor-processor "perception" linkage to achieve autonomous ground mobility coupled to an intelligent system architecture configured for:

Day, night, adverse weather semi-autonomous operations

Scaleable autonomy-vehicle infrastructure adapted to support multiple levels of autonomy from none (human operation), or remote control through semi-autonomy with infrequent low bandwidth interactions between human controller and machine, to future highly autonomous systems.

World model-based mission performance and survivability behaviours through which the intelligent vehicle can analyse the past, perceive the present, and plan for the future. The architecture will be able to assess cost, risk, and benefit of past events and future plans and will make intelligent choices between alternative courses of action.

New deployment and system interconnectivity will be made possible through micro-level technologies which will be deployed and in many instances controlled through unmanned aerial platforms.

Availability:

Estimate of technology maturity for full-scale system engineering development:

2010-2020

Impact on military ground force capability:

Close combat: Reconnaissance security and target acquisition platforms that are flexible and capable of analysis. Unmanned platforms can integrate into an advanced digital architecture to provide the manoeuvre commander low risk, high quality combat intelligence, targeting information, obstacle assessment and obstacle clearance.

Survivability: Low risk force protection.

Logistics: Automated material handling and battlefield delivery systems.

Power Projection: Easily deployable remote early access assets for initial deployment allowing additional depth and flexibility in the early stages of an operation.

5. ANNEX V - SUMMARY OF THE CRITECH EXERCISE

5.1 CONTEXT

The critical technologies exercise in selective characterisation of technologies (CRITECH), forms part of the Long-Term Scientific Study/49 (LTSS/49) entitled "Land Operations in the Year 2020". Its purpose was to assess the impact of technologies on the battlefield.

CRITECH therefore comes within the third phase of the study with the TSW seminar, to which it supplied a short list of technologies as input data.

The exercise was held in the offices of RGA Systems, at Champs sur Marne, France, during the week 19th to 23rd January 1998.

5.2 SUMMARY OF THE BOTTOM UP APPROACH ADOPTED

The initial process involved the generation of a broad list of 142 candidate technologies (see appendix 1) divided into 3 groups: group 1, electronics and computer, group 2, engineering, group 3, chemistry, biology, man-machine interface. This process created an interrogation procedure to assess, classify and select the technologies. In addition the scientists and military users who carried out the work were selected. They were provided by the 7 nations involved in the LO 2020 study. There were 8 operational specialists and 16 engineers working in policy development for technological research, and hence having a good knowledge of technologies (without being specialists in a narrow sphere) covering a relatively wide field. Participant nations could also send observers.

The second process involved providing answers to the interrogation by the group of specialists, using the exercise, christened CRITECH. From this emerged the short list of high interest technologies. It then was possible to validate the operational benefits of the technologies, through conceptual systems incorporating them, using the technology wargame (TSW), which was held in the UK between 2nd and 13th March 1998.

The third process involved a structural analysis of the items on this short list, with the aim of identifying and qualifying the lock and key technologies, during the same exercise in January 1998.

5.3 INTERROGATION

Questions concerning intrinsic value (process 2). The assessment broke down into 3 categories: feasibility, effectiveness and cost. The questions are of a closed type, that is to say they can be answered by "yes definitely", "yes in part", "no", or even "I don't know".

5.3.1 ***Feasibility***

F1 Will it have a wide range of applications?

F2 Can it be easily incorporated into existing systems?

F3 Does the acquisition of this technology alone make sense (or will it be necessary to acquire other technologies in support of it)?

F4 Is it politically acceptable?

F5 What is the earliest date for the development of a system which includes it: before 2005, between 2005 and 2015, after 2015?

5.3.2 ***Effectiveness***

E1 Will the advantage gained from this technology remain even if it is acquired by the adversary?

E2 Does it contribute to meeting an operational requirement that is partially or wholly unsatisfied?

E3 Does it improve the military effectiveness of systems?

E4 Is it resistant to counter-measures?

E5 Are you confident that this technology will have no unwanted side effects?

E6 Does this technology enable an increase in the interoperability of existing NATO systems?

E7 Will the use of this technology increase the survivability of systems?

E8 Will the use of this technology increase the availability of systems?

5.3.3 ***Cost***

C1 Will the use of this technology reduce the acquisition cost of systems?

C2 Will the use of this technology reduce the cost of use (including logistics) of systems?

C3 Does its incorporation tend to reduce the cost of system upgrade capability?

C4 Can the cost of acquiring this technology be reduced, or subsequently offset, by civil development and application (dual use)?

5.3.4 ***Assessment.***

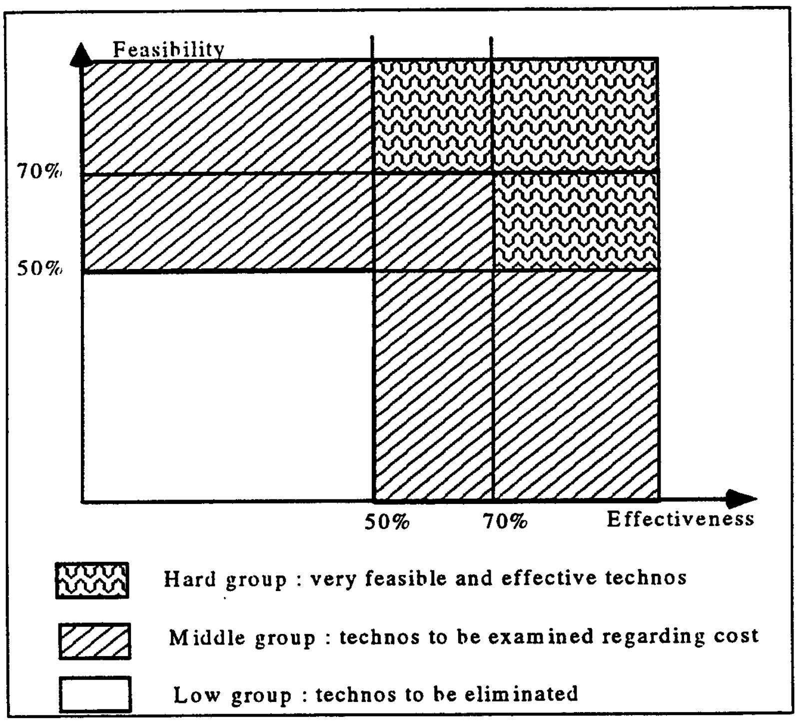
The initial amalgamation of the responses is done by computer which assesses each technology, in each category, by summing the answers to each question from each participant. A relative weighting is applied to the questions, with some having more scaling influence than others, and to the categories, as these have

the same importance but do not contain the same weighting of questions. Thus:

- questions with the greatest scaling effect (weighting of 2) : F1, E2, C1 & C2
- questions with average scaling effect (weighting of 1.5) : F5, E4, E5, & C4
- questions with the least scaling effect (weighting of 1): the remainder.

When, for each category, one adds the number of questions multiplied by their respective weightings one finds: 6.5 for feasibility and cost and 10 for effectiveness. The weighting of the categories is re-matched by applying a coefficient of (2 /1.3) to feasibility and cost.

First examination: crossover of the feasibility and effectiveness criteria.



Second examination: application of the cost criterion to technologies in the middle group.

Characterisation questions (process 3).

The questions enable an assessment of the impact of technologies of the short list on land forces. They are also of the closed type.

Q1 Will this technology contribute directly to satisfying this component of capability? (A list of 35 capability components was generated by the military specialists group in the LO 2020 study and is to be found at annex III).

Q2 Is it available today?

Q3 What effect is this technology likely to have on NATO's technological edge: it will provide a war-winning capability; it will provide significant advantages; it will

give some advantages; it is unlikely to be very useful?

Q4 Does its acquisition present risks over the time scale under consideration?

The next two questions were addressed by cross comparison with criteria already evaluated.

Q5 Is it robust? (cross between F1 and E1)

Q6 Is its procurement urgent? (cross between F2 and E2)

NATO pertinence was assessed from questions E6 and Q3. Technical/operational pertinence was assessed from questions Q5 and Q6.

5.4 OUTPUTS

5.4.1 First output.

Four groups of technologies were created (cf. appendix 2):

- hard group: 41 technologies with a high interest regarding feasibility and effectiveness (information about cost was provided too).
- soft group 1: 22 technologies with an average interest regarding feasibility and effectiveness and retained because of a good interest regarding cost or other reasons following discussions (case 115).

The short list of 63 technologies was established with these two groups. This then was the input data for the characterisation activity (process 3) and the technological wargame.

- soft group 2: 48 technologies with an average interest regarding feasibility and effectiveness but rejected because of a low interest regarding cost.
- low group : 17 technologies with a low interest regarding feasibility and effectiveness (information about cost was provided too).

A last fifth sub-group was created with 14 technologies which were deemed to be either redundant or part of other technologies in other groups.

5.4.2 Second output.

5.4.2.1 Screening based on the operational capability components.

First, the groups analysed the short list of technologies based on the 35 operational capability components. The results of this analysis appear in the form of two matrices (see appendix 3). The division of the technologies into five groups according to the results of the analysis based on the 35 operational capability components can be found in appendix 4.

One of the technologies which clearly stands apart from the rest is no. 134, "command & information systems design". This is in fact more of a system than a technology as such, which explains in part its wide range of applications.

A second group comprising six "software" fields which are also associated with command and information systems received a positive evaluation as well.

These two groups, composed of hard core technologies from the short list, constitute a series of technological systems or fields all related to operational functions which are associated directly or indirectly with C4I. This illustrates how important C4I requirements have become, both in technologies and systems and in military operations (see battlefield digitisation). Regardless of the type of conflict or crisis in which NATO forces could potentially engage, the need to control information and to dominate the adversary's information systems is crucial to a successful outcome.

The third group comprises 18 items, mostly from the hard core of the short list. Many C4I-related technologies are still present, but items associated with fire and protection functions begin to emerge. Not surprisingly, these two operational functions rank immediately below C4I in terms of the importance of requirements.

Next comes a fourth group of 25 items with a narrower range of applications that concern essentially fire, mobility and protection functions.

The final group comprises 13 technologies, some of which are related to support and others which make no direct contribution to a capability but have very broad applicability.

This classification does not as such signify that one technology is more important than another, but it does justify focusing operational and technical concerns to some extent on certain operational capability components, while revealing a certain logic in the results obtained using the exercise method.

5.4.2.2 Characterisation of key technologies

A matrix was developed in order to better visualise the results of the characterisation (see appendix 5). The 25 technologies from the first three groups established in paragraph 4.2.1 are listed vertically according to their performance with regard to the operational capability components, along with the 15 hard-core shortlisted technologies, which make up a fourth group with regard to the operational capability components. The six characterisation criteria are listed horizontally : technical relevance, operational relevance, NATO relevance, cost impact on systems, dual use (civilian/military) and feasibility/effectiveness.

All of these technologies performed well based on the criteria of technical relevance and feasibility/effectiveness (which is to be expected, given that they were already on the short list), except for no. 115 (DEW), which was referred to in paragraph 4.1. All except five (nos. 112, 126, 144, 214 and 235) met the criteria of operational and NATO relevance.

That leaves 34 key technologies to be screened based on cost (see appendix 6).

- The 23 dual-use technologies will have a lesser budgetary impact if action is taken to develop them in conjunction with civilian applications.

- There remain 11 technologies whose applications are more specifically military. Their evaluation based on cost impact was not particularly favourable. Co-operation among NATO members should make it possible to acquire these technologies and integrate them into interoperable systems at a lower cost.

APPENDICES

Appendix 1 : Broad list of 142 candidate technologies
Appendix 2 : First output : technologies division in 5 groups within 3 lists
Appendix 3 : Characterisation matrixes regarding components of capability
Appendix 4 : Short-listed technologies characterised regarding CC
Appendix 5 : Short-listed technologies characterisation matrix
Appendix 6 : Key technologies list

APPENDIX 1 to ANNEX V

BROAD TECHNOLOGIES LIST (142 ITEMS)

1. Group 1 : Electronics & software technologies (45 items)

101 Electronic Materials
102 Electrical batteries
103 Electrical power cells
104 Optical Fibre Material Devices
105 UV/Optical/IR detector materials/devices
106 Liquid Crystal Materials
107 Lasers (all types)
108 Power sources (Radio Frequency, RF, micro and mm waves)
109 Software Engineering
110 Protocols (incl. local area networks, LANs & wide area networks, WANs)
111 Computer Languages
112 Architectures
113 High Integrity Computing (incl. Safety Critical Software)
114 Secure Computing Techniques (Incl. multi-level security, MLS)
115 Directed Energy Weapon, DEW - Lasers
116 DEW - RF
117 DEW other (Particle Beams...)
118 Electronic Support Measures Communications
119 RF Sensors/Antennas - Active Radar
120 Micro & Millimetre Wave Sensors - Active Radar
121 Laser Sensors
122 IR Sensors (EO Systems)
123 UV/Visible Wave Sensors (EO Systems)
124 Acoustic Sensors Active incl. Sonar
125 Electrical Sensors
126 Explosive Detection Systems
127 Microsensors for Active Control of Structures
128 Seekers
129 Displays (Platforms, helmet.)
130 Communications Design - RF
131 Communication Design - Laser
132 Communication Design - Acoustic
133 Encryption
134 Command & Information Systems Design
135 Identification Friend or Foe/Non Co-operative Target Recognition
136 Flash memories
137 Mass storage [memories] (optical and magnetic)
138 Video servers
139 Very high power electronic components
140 Electromagnetic compatibility simulation and protection
141 Conversion of solar energy to electricity
142 Ultra-purity management systems for electronics
143 Low-cost inertial components, low-cost GPS with protection against jamming
144 High-sensitivity reception technologies
145 3D images by holography

2. Group 2 : Engineering Technologies (54 items)

201 Metals & Metal Matrix Composites (MMCs)
202 Ceramics, CMCs & Glasses
203 Polymers & Polymer Matrix Composites (PMCs)
204 Processing - Joining
205 Non-Destructive Evaluation & Life Prediction
206 Acoustic & Vibration Absorbing Materials
207 IR Absorbing Materials
208 Radar Absorbing Materials
209 Smart/Functional Materials (Sensors/Actuators/Biomimetics)
210 Propellants
211 Fuels & Lubricants
212 Explosives (incl. detonics & initiators)
213 Explosives Detection Techniques (incl. bulk & trace)
214 High Energy Physics Techniques (incl. Plasmas)
215 Fluid Dynamics Techniques
216 Warheads (all types) incl. Insensitive Munitions
217 Platform Protection Measures - Armour
218 Explosive Ordnance Disposal (EOD) Technologies
219 Gas Turbines
220 Reciprocating and rotary internal combustion engines
221 Rocket Engines & Ramjets
222 Gun Tube Propulsion - Chemical (incl. ElectroThermal Chemical)
223 Electric Propulsion (rotary-linear) (EM Launcher, Novel)
224 Transmissions/Powertrains
225 Final Drive Element (Propulsion/Track/Wheel/Rotor)
226 Ion Thrusters
227 Nuclear propulsion
228 Aerodynamic Designs
229 Structural Designs
230 Stealth Designs
231 Navigation Systems
232 Weapon Guidance & Control (for Sea, Land, Air)
233 Integrated Systems Design (incl. ElectroMagnetic Compatibility)
234 Automation & Robotics
235 Health Monitoring Systems (incl. HUMS)
236 Manufacturing Processes/Design Tools/Techniques
237 Design for Improved Reliability & Maintainability
238 Advanced Prototyping
239 Vehicle air conditioning
240 Dynamic management control of traffic flow (ex routiers)
241 Reducing the fuel consumption of vehicles
242 Clean (combustion) engine
243 Vehicle positioning e.g. by GPS
244 Reduction of automotive vehicle mass
245 Very high speed wheel-rail technologies
246 Software programs for complete material, modelling and their implementation processes
247 Materials for high-temperature processes

248 Clean and safe nuclear power
249 Optimised-performance concrete
250 Tools for understanding the structural integrity of buildings
251 Area decoys against smart shells and missiles
252 Materials and concepts for reduction of mass
253 Low-cost trajectory correction kit
254 autoguiding

3. Group 3 : Chemical, Biological & Human Technologies (43 items)

301 Chemical Agents, precursors & related materials
302 Biological Agents, precursors & related materials
303 Mid Spectrum Agents
304 Chemical & Biological Detection (CB Agents & Toxic Chemicals)
305 Database Design
306 Digital Signal Processing Techniques
307 Optical Signal Processing Techniques
308 Image/Pattern Processing Techniques
309 Speech Processing Techniques
310 Intelligent Knowledge Based Systems/Artificial Intelligence/Expert Techniques
311 Data Fusion Techniques
312 Physiological Issues
313 Psychological Issues
314 Stress effects
315 Human Computer Interfaces/Man Machine Interfaces
316 Medical materials Including Blood Products & Biomemetics
317 Chemical & Biological Sensor Systems
318 Simulators, Trainers & Synthetic Environments
319 Physical Protection Measures (eye, Body Armour..)
320 Physical Protection Measures (Diving, Life Support & Escape)
321 CB Protection-Physical (Individual Protective Equipment or Collective PC)
322 CB Countermeasures - Medical
323 Monoclonal antibodies
324 Genome cartography
325 Food preservation (high pressure, ionisation, etc)
326 Extraction purification processes
327 High-yield primary vegetable matter for biomass fuel
328 Medicines based on DNA and mapping genes
329 Rapid microbiological detection methods
330 Predictive microbiology
331 Molecular probes
332 Blood substitute
333 Cardiac substitute
334 System for producing recombining proteins
335 Non-invasive surgery techniques
336 Vaccines from genetic engineering
337 Decontamination and rehabilitation of contaminated land
338 Biological purification of water and mud treatment
339 Treatment auld quality control of drinking water

340 Intuitive logos for man-machine interface
341 Synthesis of complex molecules
342 Maintenance/rehabilitation of water supplies and drainage
343 Modelling the sociology of organisations

APPENDIX 2 to ANNEX V

SHORT TECHNOLOGIES LIST (63 ITEMS)

1. Hard group : technologies with a high interest regarding feasibility and effectiveness (41 items)

102 Electrical batteries
103 Electrical power cells
109 Software Engineering
110 Protocols (incl. local area networks, LANs & wide area networks, WANs)
112 Architectures
114 Secure Computing Techniques (Incl. multi-level security, MLS)
122 IR Sensors (EO Systems)
126 Explosive Detection Systems
130 Communications Design - RF
133 Encryption
134 Command & Information Systems Design
135 Identification Friend or Foe/Non Co-operative Target Recognition
140 Electromagnetic compatibility simulation and protection
141 Conversion of solar energy to electricity
143 Low-cost inertial components, GPS with protection against jamming
207 IR Absorbing Materials
208 Radar Absorbing Materials
213 Explosives Detection Techniques (incl. bulk & trace)
214 High Energy Physics Techniques (Inc Plasmas)
216 Warheads (all types) incl. Insensitive Munitions
217 Platform Protection Measures - Armour
229 Structural Designs
230 Stealth Designs
231 Navigation Systems
232 Weapon Guidance & Control (for Sea, Land, Air)
233 Integrated Systems Design (incl. ElectroMagnetic Compatibility)
234 Automation & Robotics
235 Health Monitoring Systems (incl. HUMS)
236 Manufacturing Processes/Design Tools/Techniques
244 Reduction of automotive vehicle mass
252 Materials and concepts for reduction of mass
304 Chemical & Biological Detection (CB Agents & Toxic Chemicals)
305 Database Design
306 Digital Signal Processing Techniques
307 Optical Signal Processing Techniques
308 Image/Pattern Processing Techniques
310 Intelligent Knowledge Based Systems/Artificial Intelligence/Expert Techniques
311 Data Fusion Techniques
315 Human Computer Interfaces/Man Machine Interfaces
318 Simulators, Trainers & Synthetic Environments
321 CB Protection-Physical (Individual Protective Equipment or Collective PC)

2. Soft group 1 : technologies with an average interest regarding feasibility and effectiveness and retained because of a good interest regarding cost (22 items)

107 Lasers (all types)
108 Power sources (Radio Frequency, RF, micro and mm waves)
113 High Integrity Computing (incl. Safety Critical Software)
115 Directed Energy Weapon, DEW - Lasers (*)
119 RF Sensors/Antennas - Active Radar
139 Very high power electronic components
144 High-sensitivity reception technologies
205 Non-Destructive Evaluation & Life Prediction
209 Smart/Functional Materials (Sensors/Actuators/Biomimetics)
224 Transmissions/Powertrains
228 Aerodynamic Designs
240 Dynamic management control of traffic flow (ex routiers)
246 Software programs for complete material, modelling and their implementation processes
247 Materials for high-temperature processes
249 Optimised-performance concrete
250 Tools for understanding the structural integrity of buildings
313 Psychological Issues
316 Medical materials Including Blood Products & Biomemetics
319 Physical Protection Measures (eye, Body Armour..)
322 CB Countermeasures - Medical
329 Rapid microbiological detection methods
336 Vaccines from genetic engineering

*** retained because of high potential interest regarding CC.**

Unretained Technologies List (79 items)

3. Soft group 2 : technologies with an average interest regarding feasibility and effectiveness but rejected because of a low interest regarding cost (48 items)

101 Electronic Materials
104 Optical Fibre Material Devices
106 Liquid Crystal Materials
111 Computer Languages
118 Electronic Support Measures Communications
120 Micro & Millimetre Wave Sensors - Active Radar
121 Laser Sensors
123 UV/Visible Wave Sensors (EO Systems)
124 Acoustic Sensors Active incl. Sonar
125 Electrical Sensors
127 Microsensors for Active Control of Structures
128 Seekers
129 Displays (Platforms, helmet..)
131 Communication Design - Laser

132 Communication Design - Acoustic
136 Flash memories
137 Mass storage [memories] (optical and magnetic)
138 Video servers
142 Ultra-purity management systems for electronics
145 3D images by holography
206 Acoustic & Vibration Absorbing Materials
210 Propellants
211 Fuels & Lubricants
212 Explosives (incl. detonics & initiators)
215 Fluid Dynamics Techniques
218 Explosive Ordnance Disposal (EOD) Technologies
220 Reciprocating and rotary internal combustion engines
222 Gun Tube Propulsion - Chemical (incl. ElectroThermal Chemical)
223 Electric Propulsion (rotary-linear) (EM Launcher, Novel)
225 Final Drive Element (Propulsion/Track/Wheel/Rotor)
241 Reducing the fuel consumption of vehicles
242 Clean (combustion) engine
251 Area decoys against smart shells and missiles
301 Chemical Agents, precursors & related materials
302 Biological Agents, precursors & related materials
303 Mid Spectrum Agents
309 Speech Processing Techniques
312 Physiological Issues
320 Physical Protection Measures (Diving, Life Support & Escape)
325 Food preservation (high pressure, ionisation, etc)
326 Extraction purification processes
331 Molecular probes
333 Cardiac substitute
335 Non-invasive surgery techniques
337 Decontamination and rehabilitation of contaminated land
338 Biological purification of water and mud treatment
339 Treatment auld quality control of drinking water
342 Maintenance/rehabilitation of water supplies and drainage

4. Low group : technologies with a low interest regarding feasibility and effectiveness (17 items)

116 DEW - RF
117 DEW other (Particle Beams...)
219 Gas Turbines
221 Rocket Engines & Ramjets
226 Ion Thrusters
227 Nuclear propulsion
239 Vehicle air conditioning
245 Very high speed wheel-rail technologies
248 Clean and safe nuclear power
323 Monoclonal antibodies
324 Genome cartography
327 High-yield primary vegetable matter for biomass fuel

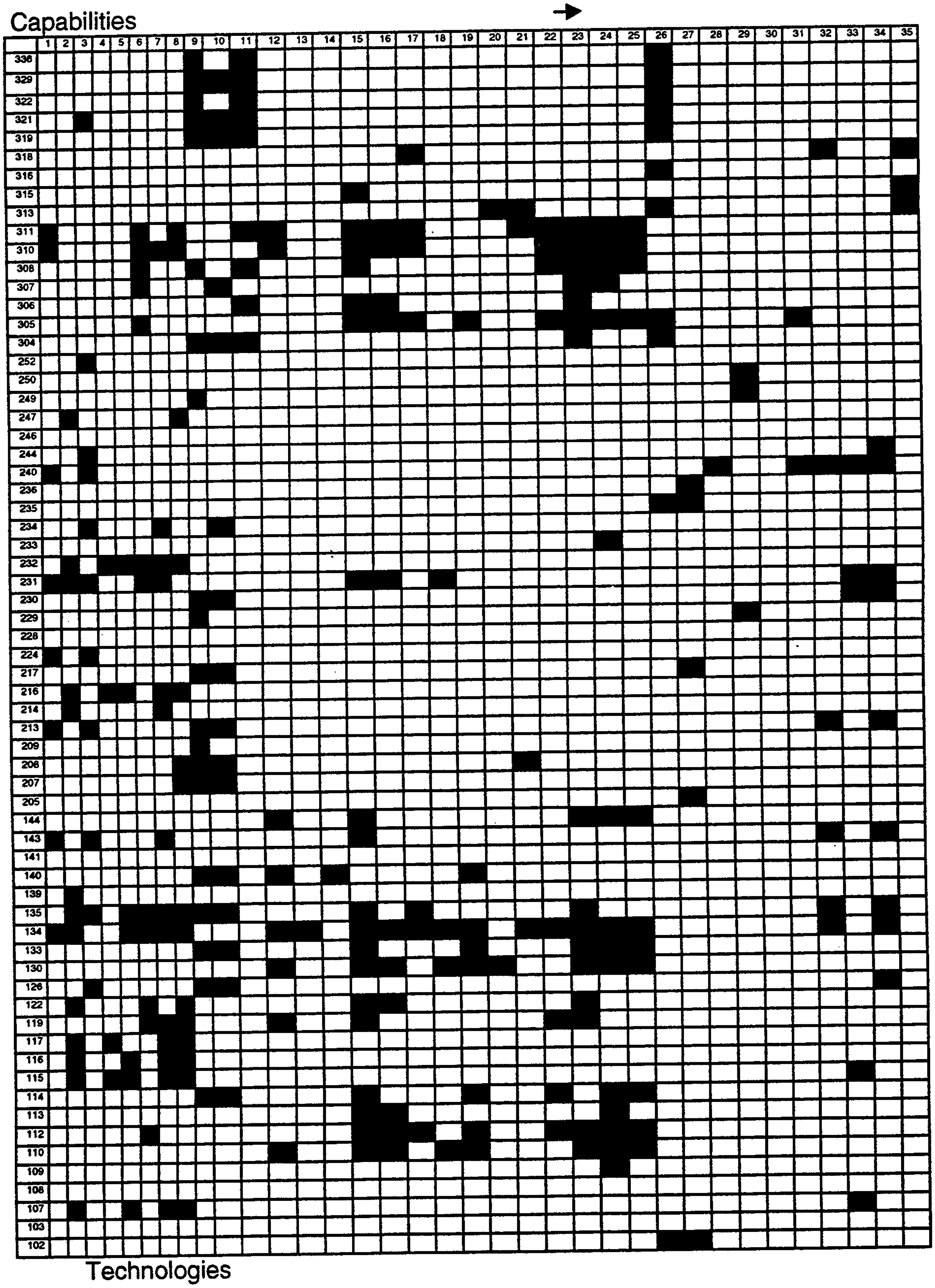
328 Medicines based on DNA and mapping genes
330 Predictive microbiology
334 System for producing recombining proteins
341 Synthesis of complex molecules
343 Modelling the sociology of organisations

5. Sub-group : technologies which are included to an other one or which appear to be redundant with an other one (14 items)

105 UV/Optical/IR detector materials/devices (122)
201 Metals & Metal Matrix Composites (MMCs) (207, 208, 252)
202 Ceramics, CMCs & Glasses (207, 208, 247, 252)
203 Polymers & Polymer Matrix Composites (PMCs) (207, 208, 252))
204 Processing - Joining
237 Design for Improved Reliability & Maintainability
238 Advanced Prototyping
243 Vehicle positioning e.g. by GPS (231)
253 Low-cost trajectory correction kit (231)
254 autoguiding (231, 234)
314 Stress effects (313)
317 Chemical & Biological Sensor Systems (304)
332 Blood substitute (316)
340 Intuitive logos for man-machine interface (315)

APPENDIX 3 to ANNEX V

Clipped covering matrix SHORT LIST TECHNOLOGIES - CAPABILITIES



[<500] ☐ [500-700] ☐ [>700] ■

APPENDIX 4 to ANNEX V

SHORT LISTED TECHNOLOGIES CARACTERISED REGARDING CC

1. top interest : technologie with an average of response > 40 (1 item)

134 Command & Information Systems Design

2. high interest : technologies with an average of response > 19 (6 items)

130 Communications Design - RF
135 Identification Friend or Foe/Non Cooperative Target Recognition
231 Navigation Systems
305 Database Design
310 Intelligent Knowledge Based Systems/Artificial Intelligence/Expert Techniques
311 Data Fusion Techniques

3. good interest : technologies with an average of response > 10 (18 items)

110 Protocols (incl local area networks, LANs & wide area networks, WANs)
112 Architectures
114 Secure Computing Techniques (Incl multi-level security, MLS)
115 Directed Energy Weapon, DEW - Lasers
119 RF Sensors/Antennas - Active Radar
122 IR Sensors (EO Systems)
126 Explosive Detection Systems
133 Encryption
143 Low-cost inertial components, GPS with protection against jamming
144 High-sensitivity reception technologies
213 Explosives Detection Techniques (incl bulk & trace)
216 Warheads (all types) incl Insensitive Munitions
232 Weapon Guidance & Control (for Sea, Land, Air)
240 Dynamic management control of traffic flow (ex routiers)
304 Chemical & Biological Detection (CB Agents & Toxic Chemicals)
308 Image/Pattern Processing Techniques
319 Physical Protection Measures (eye, Body Armour..)
321 CB Protection-Physical (Individual Protective Equipment or Collective PC)

4. low interest : technologies with an average of response > 3 (25 items)

102 Electrical batteries
107 Lasers (all types)
113 High Integrity Computing (incl Safety Critical Software)
140 Electromagnetic compatibility simulation and protection
207 IR Absorbing Materials
208 Radar Absorbing Materials
214 High Energy Physics Techniques (inlc Plasmas)
217 Platform Protection Measures - Armour
224 Transmissions/Powertrains
229 Structural Designs
230 Stealth Designs

234 Automation & Robotics

235 Health Monitoring Systems (incl HUMS)
244 Reduction of automotive vehicle mass
247 Materials for high-temperature processes
249 Optimised-performance concrete
306 Digital Signal Processing Techniques
307 Optical Signal Processing Techniques
313 Psychological Issues
315 Human Computer Interfaces/Man Machine Interfaces
316 Medical materials Including Blood Products & Biomemetics
318 Simulators, Trainers & Synthetic Environments
322 CB Countermeasures - Medical
329 Rapid microbiological detection methods
336 Vaccines from genetic engineering

5. very low interest : technologies with an average of response < 2 (13 items)

103 Electrical power cells
108 Power sources (Radio Frequency, RF, micro and mm waves)
109 Software Engineering
139 Very high power electronic components
141 Conversion of solar energy to electricity
205 Non-Destructive Evaluation & Life Prediction
209 Smart/Functional Materials (Sensors/Actuators/Biomimetics)
228 Aerodynamic Designs
233 Integrated Systems Design (incl ElectroMagnetic Compatibility)
236 Manufacturing Processes/Design Tools/Techniques
246 Software programs for complete material, modelling and their implementattion processes
250 Tools for understanding the structural integrity of buildings
252 Materials and concepts for reduction of mass

APPENDIX 5 to ANNEX V

SHORT LISTED TECHNOLOGIES CARACTERISATION MATRIX

techno	tech pert.	Op pert	Nato pert	cost imp	duality	Feas/Eff
134						
130						
135					0	
231						
305						
310						
311						
110						
112						
114						
115				0		
119						
122						
126						
133						
143						
144						
213						
216					0	
232					0	
240						
304						
308						
319						
321						
102						
140						
207						
208						
214						
217						
229						
230					0	
234						
235						
244						
306						
307						
315						
318						

Legend:

0	no relevance
	weak relevance
	good relevance
	strong relevance

KEY TECHNOLOGIES CARACTERISED REGARDING COST (34 ITEMS)

1. Dual key technologies (23 items) :

134 Command & Information Systems Design
130 Communications Design - RF
231 Navigation Systems
305 Database Design
310 Intelligent Knowledge Based Systems/Artificial Intelligence/Expert Techniques
311 Data Fusion Techniques
110 Protocols (incl local area networks, LANs & wide area networks, WANs)
114 Secure Computing Techniques (Incl multi-level security, MLS)
119 RF Sensors/Antennas - Active Radar
122 IR Sensors (EO Systems)
133 Encryption
143 Low-cost inertial components, GPS with protection against jamming
240 Dynamic management control of traffic flow (ex routiers)
304 Chemical & Biological Detection (CB Agents & Toxic Chemicals)
308 Image/Pattern Processing Techniques
102 Electrical batteries
229 Structural Designs
234 Automation & Robotics
244 Reduction of automotive vehicle mass
306 Digital Signal Processing Techniques
307 Optical Signal Processing Techniques
315 Human Computer Interfaces/Man Machine Interfaces
318 Simulators, Trainers & Synthetic Environments

2. Military applicative key technologies (11 items) :

135 Identification Friend or Foe/Non Cooperative Target Recognition
213 Explosives Detection Techniques (incl bulk & trace)
216 Warheads (all types) incl Insensitive Munitions
232 Weapon Guidance & Control (for Sea, Land, Air)
319 Physical Protection Measures (eye, Body Armour..)
321 CB Protection-Physical (Individual Protective Equipment or Collective PC)
140 Electromagnetic compatibility simulation and protection
207 IR Absorbing Materials
208 Radar Absorbing Materials
217 Platform Protection Measures - Armour
230 Stealth Designs

6. ANNEX VI -TECHNOLOGY SEMINAR WARGAME

6.1 INTRODUCTION

6.1.1 Background

Land Operations 2020 (LO2020) is a North Atlantic Treaty Organisation (NATO) study whose customer is the Supreme Headquarters Allied Powers Europe (SHAPE). The technical authority for the study is NATO Systems, Analysis and Simulations (SAS-006), formerly Defence Research Group (DRG) Panel I (LTSS/49). The LO2020 Study's final report is to be submitted to the NATO SAS-006 in time for it to be sent to SHAPE by 1 Dec 98 The report should assist SHAPE to determine their long term requirements and provide some guidance for NATO's defence planning.

The study purpose is to identify the types of technologies that could provide a significant impact on the NATO 2020 battlefields. The long term aim of LO2020 is to identify the land forces, their capabilities and their characteristics, for warfighting and other military operations. More specifically, its objectives are to:

- Identify potential emergent and key technologies for the 2020 timeframe;
- Select those technologies which should make a significant contribution to the land battle for 2020;
- Make recommendations for future allied and national research programmes.

The UK's LO2020 Study Team Leader tasked the DERA Centre for Defence Analysis (CDA)(Land) to examine the most appropriate way that Operational Analysis (OA) could support the LO2020 Study. The former NATO DRG Panel VII fully endorsed the need for OA to support the LO2020 Study and the UK Panel VII representative played an active part in the UK's deliberations on the most appropriate OA techniques, given the limited timescale (less than 1 year).

An UK steering committee was established to oversee the study and provide a focal point for decision making. The committee met on two occasions.

This annex is a copy of the Final Report[6] less its annexes, which include the outcome of the TSW structural discussions.

6.1.2 Aim

The aim of the CDA (Land) study was to provide support to the LO 2020 study group in formulating its recommendation for the balance of investment in future research.

[6] Land Operations 2020 Technology Seminar Wargaming Final Report, LSS 310 M82802, dated July 1998.

6.1.3 Objectives

The study was planned to:

- assess the relative merits of agreed systems;
- rank systems overall and by scenarios/players specialisation;
- rank the component technologies.

6.2 METHODOLOGY

6.2.1 Selection

CDA (Land) organised a study day attended by a small number of suitable participants from the Ministry of Defence (MOD) and DERA to define the characteristics which an appropriate OA approach should consider and how these might be satisfied by one or more OA methods. The recommendation from this activity was that a combination of a Technology Seminar Wargames (TSWs) and Saaty's Analytical Hierarchy Process might be used to provide guidance within the NATO study's timescales.

The use of simulation as part of the methodology was considered at an early stage but it was rejected because it requires detailed system data and tactical understanding to construct a suitable model. It was determined that the nature of the battlefield systems under consideration was innovative, novel and likely to be less well defined and understood than would be necessary for the establishment of a simulation model. The TSW technique is particularly well suited to examining less well-defined systems.

6.2.2 Overview

The OA study to support the LO 2020 study consisted, essentially, of three Technology Seminar Wargames (TSWs). Each TSW was conducted in a different scenario or setting by a combined military/civilian team. Three teams, two BLUE and one RED independently assessed the relative values of a number of battlefield systems when deployed against RED forces in a snapshot from each scenario. After a discussion period teams participated in a plenary session where there was an opportunity to discuss, in a wider forum, the advantages and disadvantages of the candidate systems. A team of notetakers recorded both the team and group discussions. At the end of each gaming day each participant individually performed a pairwise comparison using the Saaty Analytical Hierarchy Process (AHP) to judge the relative values of one system against another in the context of a number of differing criteria. On the final day a further individual pairwise comparison was completed by each participant taking into account all the factors that had been considered over the previous gaming periods.

6.2.3 Application of technology seminar wargaming in the study

The key element in the study was the use of the TSW to judge, in a structured format, the relative military advantages of the candidate systems under

assessment. The form which a TSW takes can be fairly flexible and can be tailored to the problem. In all cases however, it is a means of structuring discussion by one or more teams of experts. In the course of this study the teams were presented descriptions of scenarios and information about the forces depicted in these scenarios (e.g. aim and objectives, organisational structure, assets available and their capabilities). The teams were presented with a military problem and had to consider the technology issues in relation to the problem. For example, what were the relative strengths and weaknesses of various novel weapon systems, what was likely to be the best way to use novel systems tactically and how would the novel systems operated by an opponent best be countered by an enemy?

Each game proceeded initially in 'closed' mode with each team ignorant of the other teams' discussions. Then the teams were brought together to share their conclusions, and discuss and explore the reasons for differences. These discussions were recorded by notetakers.

TSWs were played over a number of days, during which time three scenarios and a number of excursions were considered.

6.2.4 ***Pair-wise comparisons - the Saaty Analytical Hierarchy Process***

The purpose of a pair-wise comparison technique is to obtain a ranking of options. It does this by considering in turn single pairs of options and asking which of the two options is of greater 'value' when judged by a specified criterion. The Analytical Hierarchy Process (AHP) developed by Saaty is one such method which also estimates how much better one option is than another. It can also be used for judging options by a number of criteria and to generate a single ranking weighted across those criteria. The method therefore met the requirements for the form of output required by the LO 2020 study. However, it must be remembered that it is a means of eliciting subjective judgements in a quantitative form: its results remain subjective.

A software package which implements the AHP method was obtained. This AHP 'package' (Expert Choice) was quick and easy to use on a portable PC.

6.2.5 ***Study constraints***

Although the technologies, costs and risks of the candidate battlefield systems were assessed prior to the TSW, the time available for player participation in the TSW was still a constraint. It was therefore necessary to restrict the number of individual pairwise comparisons undertaken to the minimum consistent with the collection of worthwhile data.

6.2.6 ***Assessment criteria***

Military

Key to the effective application of the TSW was the selection of appropriate criteria within which to compare the battlefield systems. Eight prime criteria were identified and labelled: the military 'Components of Capability':

- Manoeuvre;
- Fire support;
- Protection;
- Control of the EM Spectrum;
- Command and Control;
- Information and Intelligence;
- Sustainability;
- Deployability.

As this was supporting a NATO study and had a number of NATO participants, the NATO version of the components of capability was used throughout the study. For assessment purposes all the components of capability were equally weighted.

Technology: A number of important criteria which together contributed to the 'technical attractiveness' of a battlefield system. They were defined as:

Technology advance: Technology advance provides a measure of whether the research work being requested by the military sponsor provides an intellectually demanding challenge to the research team and provides the basis for significant further novel research. Technology advance comprises two elements. The first is advance in technologies (or a key technology). The second element concerns the complexity of the systems integration. When both elements are present and pose significant challenges this indicates very high technology advance.

Robustness: Robustness provides a measure of whether the research work is likely to provide a reliable ruggedised product to withstand the military environment. It also embraces reliability. It concerns the impact of the military environment on the technologies comprising the concept. Will the equipment withstand the temperature extremes, vibration, shock impact, weather, dust, mud, sand? Will the equipment provide high reliability in-service?

[Note: This definition excludes robustness against countermeasures which was considered to be part of the scope of military attractiveness.]

Technical utility: Technical utility is high if the component technologies have a wide applicability across a range of different military applications."

These definitions were used by a team of technologists when assessing the technological attractiveness of the battlefield systems used in the TSW.

Risk: Risk was assessed as high, medium or low by the same team of technologists who had assessed technological attractiveness. They were asked to assess the systems according to the following definition:

> "Assess the above systems as a procurement risk [which is the overall assessment of the likelihood of success of fielding the equipments/systems embodying the concepts by 2020]. The assessment of procurement risk therefore should take account of the level of technical risk during the research and demonstration phases, the development and manufacture stage and the likely robustness and reliability in the military environment. Technical risk at the research and demonstration stage is concerned with the level of complexity of systems integration and the risk that individual technologies will not be advanced sufficiently to achieve the concept by 2020. Also, a further risk at the demonstration phase is that the laboratory proof of principle cannot be successfully scaled up."

Cost: Battlefield systems costs were assessed separately using a relative scaling based on the top 100 programmes in the research programme to give indicative research costs and the top 100 programmes in the equipment programme to give indicative equipment costs. Costs were assessed as being high, medium-high, medium, medium-low or low.

6.2.7 ***Scenarios***

Scenario selection and definition was a joint activity between the Directorate of Land Warfare (DLW) and CDA (Land) military staff. Scenario selection and excursions were agreed by the steering committee.

Three scenarios were examined: two of regional conflict, one at divisional level, denoted as day 1, the other at brigade level in the same setting, denoted as day 2, and one operation other than war (OOTW), denoted as day 3. The scenarios were generic and the names of major features were changed to cater for national sensitivities. For each of the three scenarios a single basic outline plan was developed. To cater for as many variations in weather, terrain and types of action as possible either excursions were made from the basic plan to cover these variables, or the questions posed to the teams asked them to specifically consider these factors. Questions were framed to cover both the main scenario themes and excursions to these themes.

6.2.8 ***Battlefield systems and technologies***

Since it was not meaningful for technologies to be assessed independently from physical applications, the assessment had to be of battlefield systems, not technologies. It was therefore necessary to postulate systems and be able to identify which technologies (or self-contained sub-technologies within these) each battlefield system depended upon. The output from the TSW was designed to rank battlefield systems, and hence it would be possible to rank sets of technologies/sub-technologies, each set corresponding to a battlefield system.

Early work to identify the required capabilities and characteristics of land forces had been undertaken as part of the NATO study. The TSW involved matching technologies to the force capability characteristics that had been identified by the MSG. The French led CRITECH Exercise in support of the LO2020 Study, described in Annex V, identified about 50 technologies of high interest which were used to generate a list of battlefield systems that incorporated them.

Prior to the TSW a team with representatives from Defence Evaluation Research Agency (DERA), and MoD HQ-Sciences (Land) were responsible for the final selection of the battlefield systems to be assessed in the TSW. Twelve battlefield systems were selected from the wide range of over 40 battlefield systems that were generated by the nations participating in LO2020. Each battlefield system had a list of component technologies associated with it. In selecting the battlefield systems for assessment it was assumed that the systems would be operating on a digitized battlefield and that Future Infantry Soldier Technologies (FIST) would be in place. Given the format and aims of this TSW it was not thought practical to attempt to assess Command, Control and Information Systems.

The twelve battlefield systems selected for the TSW are shown in Table 6-1:

System	Title	Brief Description
TSW-1	High Mobility Vehicle	A modular system of high mobility vehicles with a light cannon weapon fit, able to travel at twice the present speed across country.
TSW-2	Concrete Foam	Stored in cans of various sizes, when released a foam develops and hardens.
TSW-3	Non-Lethal Barrier	An invisible polymeric powder which is sprayed onto roads or other surfaces to which, when wetted, it strongly adheres. Removed by biologically engineered micro-organisms which digest it, leaving a harmless residue.
TSW-4	Electric Direct Fire Heavy Weapons Platform	Electric drives, electric armour, 50 tonnes; 100 mm electromagnetic rail gun.
TSW-5	Modular UAV	The ground force's highest flying organic UAV. A multi-sensor platform with a weapons capability.
TSW-6	RF Directed Energy Weapon	RF radiation via a multi-horn "phased array", vehicle mounted point defence system with a soft kill capability against missiles, attack helicopter, fixed wing and land vehicles up to 5km range.
TSW-7	EO Sensor Dazzler	A man portable system which delivers high power laser radiation against variety of targets (as for TSW-6) with the intention of damaging their sighting system.
TSW-8	Unattended Robot Ground Weapon	Organic indirect fire system for manoeuvre units.
TSW-9	Advanced Artillery System	The ETC gun is basically the same size as a conventional artillery piece, such as AS90, but has greater range and accuracy. Its munitions can be course corrected and it uses a RF munition to attack C3 targets.
TSW-10	Micro Electrical Mechanical Systems (MEMS)	A field of unattended, small (cm size) MEMS based sensors which act co-operatively, communicate covertly and detect enemy vehicles or soldiers.
TSW-11	Indoors/Outdoors UAV	A small aerial robot equipped with video cameras, for surveillance or reconnaissance of operational areas inside and outside buildings
TSW-12	Robot Sentry	A relatively small robot moving on wheels and equipped with an automatic gun and CCD video cameras; remotely piloted for scouting in urban zones.

Table 6-1 - Twelve battlefield systems assessed in the TSW

To enable the players to game the battlefield systems effectively the systems were specified in greater detail in a data sheet of 2 or 3 pages. At the request of the players, an additional synopsis of each system was produced that contained the main characteristics of the systems.

Prior to the TSW, the battlefield systems were mapped onto their respective components of capability by DLW, CDA (Land) and LS/CSD. Some battlefield systems had applicability over several components of capability and a few were mapped on to only two.

The ORBATS used during the TSW were based on the View 1 Division ORBATS produced by DLW and described in the British Army 2000 Paper. This Paper introduces proposed ORBATs for 2010 and beyond. These ORBATS are resource constrained and this constraint was carried forward into the TSW. Manpower was used as the main parameter (rather than cost) to determine the number of equipments of each novel system played in the TSW.

The battlefield systems examined in the TSW were mapped on to the 2010 ORBATs in appropriate quantities although it was accepted that one of the conclusions of the TSW could be a recognition that the incorporation of a new system into the ORBAT might precipitate a consequent change in the ORBAT to gain the most benefit. War games provide a good means of examining the suitability of ORBATs, but this would have to be at a later stage of work. In the TSW, a fixed ORBAT allowed the relative merits of the systems to be examined. In practice the level of resolution of the game did not require more than outline, indicative ORBATs.

6.2.9 ***Assessment***

Having established the technological attractiveness, risks of the battlefield systems and costs prior to the main gaming phase it was then necessary to establish a structured procedure for assessing the military attractiveness during the gaming phase. This was carried out in two parts; a discussion period, part in teams and part as a full group session, and an individual ranking exercise using the Saaty pairwise comparison methodology. The results of the discussion phase were recorded by notetakers and the pairwise comparisons were collated mathematically using software specifically designed for this purpose.

Two secondary but useful assessments were also carried out on the final day of the TSW. First, players were asked, on an individual basis, to compare all the battlefield systems under consideration but assessing relative military attractiveness across the single combined criteria of all possible scenarios and all military components of capability. The second assessment asked the players to rank the TSW battlefield concepts against the systems expected to be in service in 2020 and called, for simplicity, the 'legacy systems'. These were the systems that were either in service now and expected still to be in service in 2020, or

systems that were not part of the TSW but were already well established in the procurement process, for example the attack helicopter.

6.2.10 ***Team composition***

For the TSW, two teams representing Blue were established together with a team representing Red. Composition of the teams was as follows:

BLUE 1

- a representative of Directorate Science Land, MoD HQ
- a CDA representative;
- a technologist, at grade 6 or 7 level;
- a military officer at full Colonel level;
- an officer from DLW;
- NATO Rep (US);
- NATO Rep (GE).

BLUE 2

- a representative of Directorate Science Land, MoD HQ
- a CDA representative;
- a technologist, at grade 6 or 7 level;
- a military officer at full Colonel level;
- an officer from CDA(Land) at Lt Colonel level;
- NATO Rep (FR);
- NATO Rep (CA).

RED

- a CDA representative;
- representative from the Conflict Studies Research Centre
- a technologist at grade 6 or 7 level;
- an appropriate military officer at Lt Col level;
- a representative from DI to advise on RED behaviour.

Appointments in the teams were determined by suitability, experience and availability. There were only two changes made to the teams during the TSW due to individuals' prior work engagements but the overall continuity was not affected.

6.2.11 ***Observers***

Generally, observers were not encouraged because previous experience conducting TSWs indicated that they would be liable to distract the teams'

players. To cater for those observers from NATO who had expressed a desire to visit, a specific day was set aside to allow them both to be briefed and to observe gaming in a controlled fashion. In the event the observers did not provide an undue distraction and they were able to add useful comment to the plenary sessions. Although they were asked to complete a pairwise comparison at the end of their day's observing, only the results of expert observers have been included.

6.3 STUDY RESULTS

6.3.1 Overview

Technical attractiveness: The technological assessment of the battlefield systems was conducted by nine DERA technologists using the criteria described under the assessment criteria for technology for the Saaty AHP. TSW-4, the Electric Direct Fire Heavy Weapons Platform and TSW-10 the Micro Electrical and Mechanical Systems were rated equally as the highest scoring systems and TSW-7, the EO Sensor Dazzler the lowest scoring system with TSW-2, Concrete Foam only scoring marginally higher. However, technical attractiveness does not provide an overall rating of the merits of the research work for the concepts because it excludes consideration of the likelihood of success and does not take into account the cost of the research. Further post-analysis work has been carried out to illustrate the impact of cost and risk on potential investment decisions, and this is reported at the end of this Annex.

Military attractiveness: The main thrust of the TSW was to assess the military attractiveness of the concept systems. The most important part of the TSW was the separate team discussion periods and the plenary sessions, which all the teams attended. The important points of these discussions were recorded by a team of note takers who had been allocated two per Blue team and one for Red. On the next working day following the TSW gaming period the note takers gathered to collate and record the points raised by their respective teams. These notes were collated by individual scenario and form the basis for the judgements expressed in this report.

The pairwise comparisons carried out by the players and expert observers during the TSW provide a more quantitative assessment of the players' opinions when assessing the relative military attractiveness of the battlefield systems but these results needed to be assessed in conjunction with the judgements expressed by the players during the discussion periods. Overall, there is a close correlation between the two outputs from the study. The assessment of military attractiveness rated highly the High Mobility Vehicle and the Modular UAV. Grouped as a second priority were the Electric Direct Fire Heavy Weapons Platform, MEMS, the Robot Ground Weapon, Advanced Artillery System and Concrete Foam.

6.3.2 Judgement and discussion

The Blue and Red team arrangement allowed for a good discussion period to develop when the scenarios and questions were examined in detail. After

experiences of the first day more time was allotted to team discussions at the expense of the plenary sessions. Even more time would have been useful to explore some issues fully. The full list of comments recorded by the note takers is available in the full DERA report, referenced earlier.

6.3.3 *Initial pairwise comparisons*

As described earlier, pairwise comparisons were completed, on an individual basis, at the end of each scenario and as a final all embracing assessment. These results have been assessed in conjunction with the judgmental comments.

6.3.4 *Military attractiveness*

Overview of systems, in terms of ranking for each scenario and general comments is given in table 2 below.

System no	Title	Comments	Scenario ranking		
			Day 1	Day 2	Day 3
TSW-1	High Mobility Vehicle	Although not reflected in the level of team and group discussion, the High Mobility Vehicle concept scored consistently well in the pairwise comparisons.	1	1	1
TSW-2	Concrete Foam	Although a number of useful possible applications were put forward, Concrete Foam was only seriously discussed when its application as a river crossing aid was considered. It tended to be regarded as a useful supporting system to the main battlefield systems.	5=	5	3
TSW-3	Non-Lethal Barrier	As a concept the Non-Lethal Barrier was well regarded but the current characteristics were not well liked.	12	11	11

TSW-4	Electric Direct Fire Heavy Weapons Platform	The Electric Direct Fire Heavy Weapons platform was well discussed both during the team considerations and in the plenary sessions. There was considerable discussion as to the relative merits of a weapon platform of this nature on the battlefield in 2020 and it was generally less well regarded than the AH and other mobility assets. The final pairwise comparison ranked this system well behind that of the Modular UAV and the High Mobility Vehicle.	3	3	5
TSW-5	Modular UAV	The modular UAV scored highly in all scenarios reflecting a need to win the battle for information. If a weapon fit could be incorporated then this would be a useful combined capability.	2	2	2
TSW-6	RF Directed Energy Weapon	The RF DEW Weapon was hampered by a perceived lack of mobility, but it was rated highly in its ability to attack AH and as a counter to enemy ISTAR. Overall, an RF capability was perceived to be a very attractive option if it could be delivered accurately. In its current configuration it did not rate highly overall.	8	8	8
TSW-7	EO Sensor Dazzler	The EO Sensor Dazzler demonstrated better utility in the OOTW scenario than in the higher intensity conflict but possible legal/political objections were raised several times in discussion.	9	9	10
TSW-8	Unattended Robot Ground Weapon	The Robot Ground Weapon System was credited with a wide range of roles including that of an aviation minefield.	5=	6=	9

TSW-9	Advanced Artillery System	The RF round of the Advanced Artillery System was thought to have good utility.	5=	4	6
TSW-10	Micro Electrical Mechanical Systems (MEMS)	The MEMS concept was well liked and provoked considerable discussion. There were a number of novel applications put forward and this system was thought to have both wide battlefield utility and a synergy with other concept and legacy systems.	4	6=	4
TSW-11	Indoors/ Outdoors UAV	The Indoors/Outdoors UAV was less well regarded than the Modular UAV but was thought to be a useful asset in close or urban terrain.	10	10	7
TSW-12	Robot Sentry	With only a reduction in manpower as a main advantage the Robot Sentry was seen as having no great advantage over current capabilities.	11	12	12

Table 6-2 - Overview of Systems

Statistical analysis-between scenarios: To examine whether there was any statistical difference between the results from the three scenarios a statistical test (a one way Analysis of Variance [ANOVA]) has been undertaken on the results. This indicates that there is a difference, significant at the 5% level, between the results for some of the battlefield systems over the three scenarios, indicating that most, but not all systems, are scenario dependent. Statistical differences between days are indicated by ticks in the table 3 below:

	Days 1 and 2	Days 2 and 3	Days 1 and 3
TSW 1	✓	✓	✓
TSW-2			
TSW-3			
TSW 4	✓		✓
TSW 5	✓		
TSW-6			
TSW 7			✓
TSW 8		✓	✓
TSW 9			✓
TSW 10	✓		
TSW 11		✓	✓
TSW 12		✓	✓

Table 6-3 - Indication of Statistical Significance between Scenarios

Using this test indicates that TSWs 2, Concrete Foam, 3, Non -Lethal Barrier, and 6, RF DEW Weapon were not scenario dependent.

A further statistical test (the two way ANOVA) was carried out on all the systems together over the three scenarios. This indicated that there was a statistical difference, significant at the 5% level, between the scenarios as a whole and this was supported by the Wilcoxon one way signed rank test which also indicates that there is a statistical difference between the scenarios.

Statistical analysis-variance between teams: To examine whether the results may have been influenced by personalities or team dynamics the separate results of the two Blue teams and the Red team have been examined. Examination of the results indicates a close consensus between the three teams.

Statistical analysis-variance between players' speciality: To examine whether the ranking of the battlefield systems in each of the scenarios differed between players of differing backgrounds, the results were separated into those players from military, analytical (CDA) and technological backgrounds. Examination of the results indicates a close consensus between the three disciplines represented within the teams.

6.3.5 ***Technical attractiveness***

ADSc (L) 4, TM/LS/CSD, five representatives from CDA (Land) and 4 technologists were present at a meeting to assess the technological attractiveness of the candidate battlefield systems and their technical risk. After the systems had been described in outline by TM LS/CSD, subject matter experts were able to describe certain aspects in more detail. A question and answer session followed. The comments from this session were recorded by two CDA (Land) notetakers.

The main points from these discussions were:

- the High Mobility Vehicle would have high survivability but low sustainability;
- the logistics of covering an entire minefield with Concrete Foam were considerable and such a use would only neutralise pressure fuzed mines;
- the materials for the Non-Lethal barrier were currently available but a suitable deployment system had yet to be developed;
- although it was commented that the Electric Direct Fire Heavy Weapons Platform could swim only if it had floats, it was thought that at a weight of 50 tonnes swimming was an unlikely option. The majority of the 50 tonnes was taken up by the pulsed power supply;
- an EM gun might not be able to use guided rounds;
- cooling would be a problem for the EM gun;
- the provision of power for pulsed weapons was a major problem and significant funding would be required to develop a workable system by 2020. It was, however acknowledged that if high temperature superconductivity became available then most of the concepts would be achievable. The effect of very high magnetic fields on humans could pose a problem;
- the utility of the modular UAV would be substantially reduced if it required a runway to operate from;
- it was thought that it could be difficult to assess whether the EO Sensor Dazzler had been effective when used;
- for the MEMS Sensor field to operate effectively, the sensors must act collectively. Spurious signals and antenna technology were also problems with this system.
- To maximise the potential of some future weapon systems on the battlefield of the future the most difficult challenge to be faced is the need for pulsed power technology of a practicable size, weight and performance.

When assessed against the technical criteria outlined earlier the 12 battlefield systems were ranked as follows:

Ranking:[7]	Concept:	
=1	TSW-4	Electric Direct Fire Heavy Weapons Platform;
=1	TSW-10	Micro Electrical and Mechanical Systems;
3	TSW-8	Robot Ground Weapon System;
4	TSW- 6	RF DEW
5	TSW-5	Modular UAV;
=6	TSW-3	Non-Lethal Barrier;
=6	TSW-9	Advanced Artillery System;
8	TSW-11	Indoors/Outdoors UAV;
9	TSW-12	Robot Sentry;
10	TSW-1	High Mobility Vehicle;
=11	TSW-7	EO Sensor Dazzler;
=11	TSW-2	Concrete Foam.

Technical risk: Technical risk was also assessed during the technological assessment period with a high, medium and low scoring system. To assess the results that included shadings on these ratings a scale of 1-5 was used to score the battlefield systems and rank them in terms of risk (see Table 6-1).

Technical attractiveness as defined earlier comprises technology advance, robustness and technical utility. Technical risk of the research and the subsequent stages of procurement associated with each concept and the estimated cost of research programmes have been assessed and are shown separately for each concept in Table 6-1. The ranking of concepts by technical attractiveness alone, shown by Figures 1-3, does not provide an overall measure of the merit of the research programmes. Further work has been done to illustrate the impact of risk and cost on potential funding decisions.

Battlefield systems costs: The estimated costs of each of the battlefield systems are outlined together with the associated technical risk and overall technical attractiveness in Table 6-4:

[7] "=" indicates concepts are of equal ranking

Technical Attractiveness Ranking	Technical Risk Ranking	System Costs	
		Research	Equipment
1st TSW-4	H	H	H
1st TSW-10	M	ML	L
3rd TSW-8	M	H	H
4th TSW-6	H	MH	M
5th TSW-5	H	MH	MH
6th TSW-3	L	L	L
6th TSW-9	M	MH	H
8th TSW-11	M	ML	L
9th TSW-12	L	ML	L
10th TSW-1	M	MH	H
11th TSW-2	L	L	L
11th TSW-7	M	M	ML

Key: TSW-4 Electric Direct Fire Heavy Weapons Platform; TSW-10 Micro Electrical and Mechanical Systems; TSW-8 Robot Ground Weapon System; TSW- 6 RF DEW; TSW-5 Modular UAV; TSW-3 Non-Lethal Barrier; TSW-9 Advanced Artillery System; TSW-11 Indoors/Outdoors UAV; TSW-12 Robot Sentry; TSW-1 High Mobility Vehicle; TSW-7 EO Sensor Dazzler; TSW-2 Concrete Foam.

Table 6-4 - Technical Attractiveness Ranking of Battlefield Systems

Examination of Table 6-1 highlights that those systems that have a high cost tend to be those that have a high technical attractiveness.

6.3.6 **Graphical representation of results**

A graphical representation of the technical attractiveness versus military attractiveness results is shown below in Figures 1-3. These results are plotted on a normalised scale where 1 indicates the highest scoring system and other systems are normalised with respect to this.

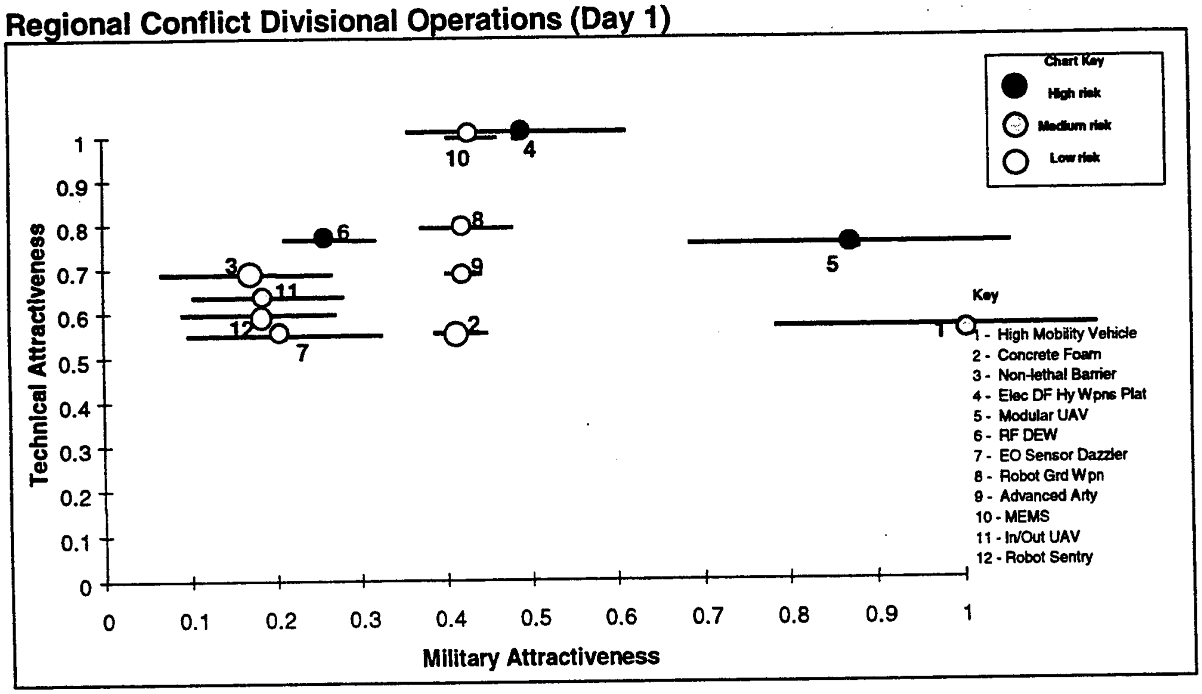


Figure 6-1 - Technical v. Military Attractiveness Results for Day 1

Note 1: Horizontal lines represent error bars of +/- 2 standard deviations.

Note 2: 'Technical Attractiveness' does not provide an overall rating of the merits of the research work for the concepts because it excludes consideration of the likelihood of success and does not take account of the cost of research. Also, there may be a case for including consideration of the predicted percentage system performance improvement due to the research, although it may be argued that this factor is already included in the assessment of military attractiveness for the concepts. More work is required to provide an overall assessment of the merits of the research work for the concepts.

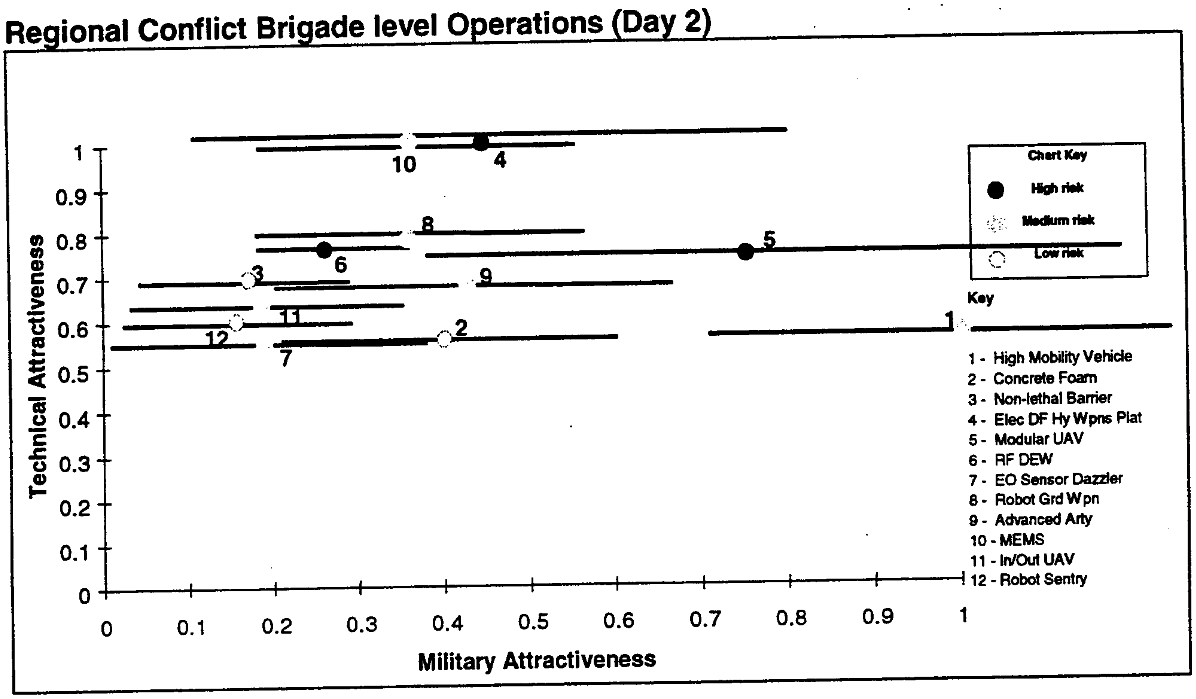


Figure 6-2 - Technical v. Military Attractiveness Results for Day 2

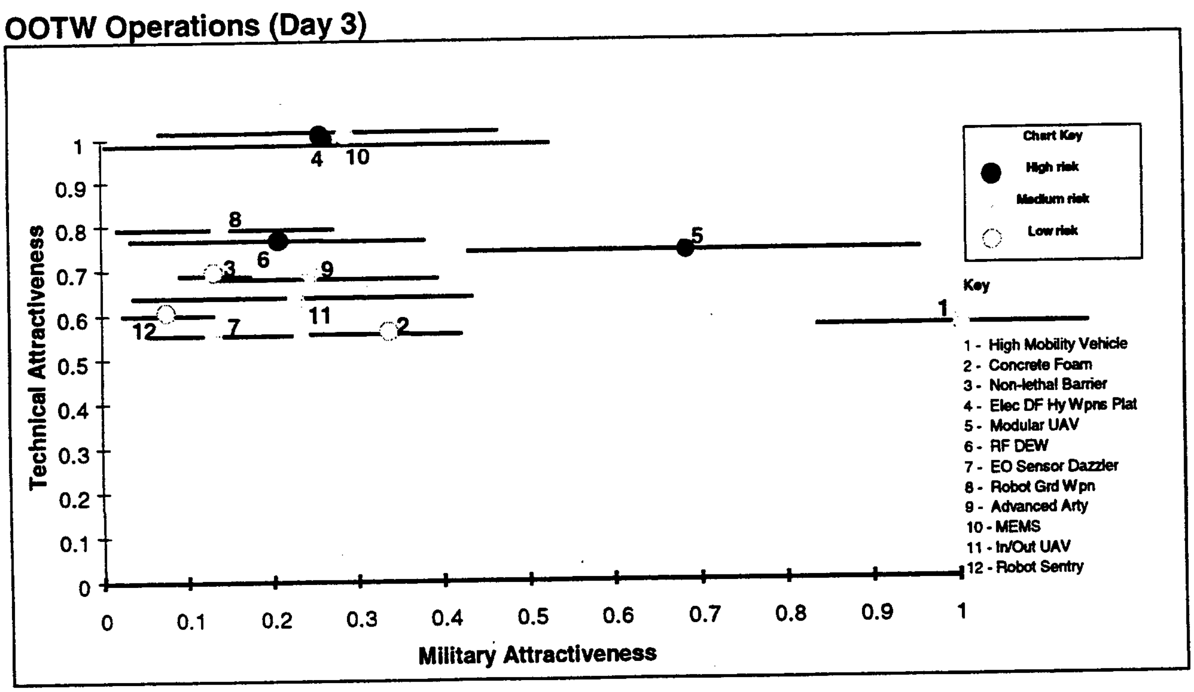


Figure 6-3 - Technical v. Military Attractiveness Results for Day 3

6.3.7 ***Excursions to pairwise comparison results***

As a confidence building measure to ensure that the components of capability, which were used as the main assessment criteria for military attractiveness, were being correctly applied, the individual results for each component of capability were grouped in four categories. The results in these categories were then assessed for consistency. Overall there was good consistency of ranking when battlefield systems were compared with the components of capability.

6.3.8 ***Comparison with legacy systems***

In order to compare the players' opinion of the relative worth of the battlefield systems with existing or planned systems, players were asked to rank the TSW battlefield systems alongside 'legacy systems' that were either in service or planned to enter service by 2020. The results also provide a separate, non-comparative, ranking of the TSW battlefield systems. These results are shown in Figure 6-4 below.

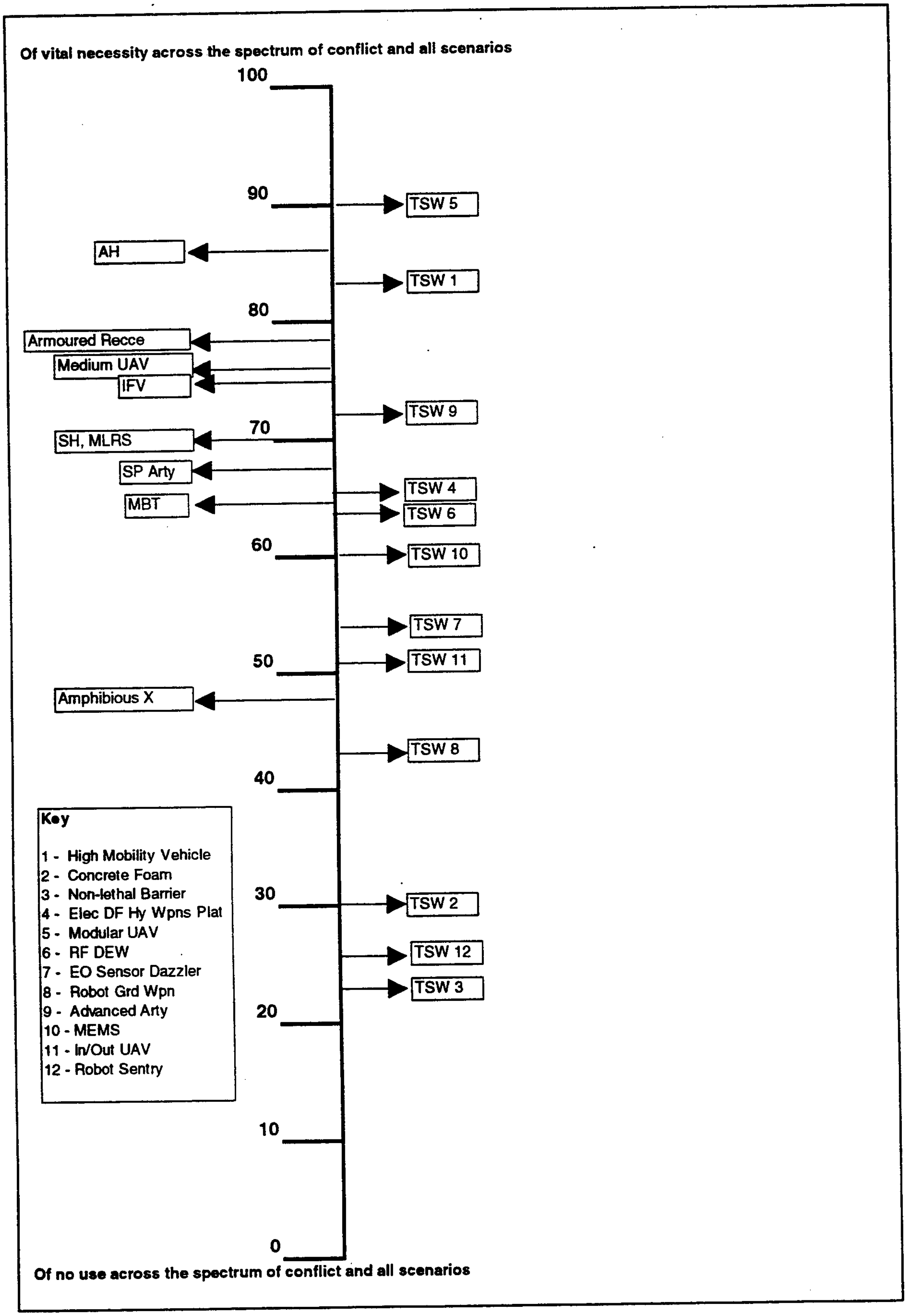


Figure 6-4- Comparison of Legacy Systems with TSW Systems

TSW-5, the Modular UAV, is ranked above the AH and TSW-1, the High Mobility Vehicle, above that of armoured reconnaissance (TRACER) and the MBT (CR2). TSW-9, the Advanced Artillery System is preferred to MLRS and the current AS90 system.

6.3.9 ***Ranking of technologies***

Whilst the aim of the TSW was to achieve a ranking of battlefield systems, the study aim was to assess which technologies offer the best overall return on investment. It is therefore necessary to decompose the battlefield systems into their respective technologies.

Figure 6-5 below indicates that the systems fall approximately into, in terms of military attractiveness, three groups. Similar groupings can be identified from the results for the other scenarios.

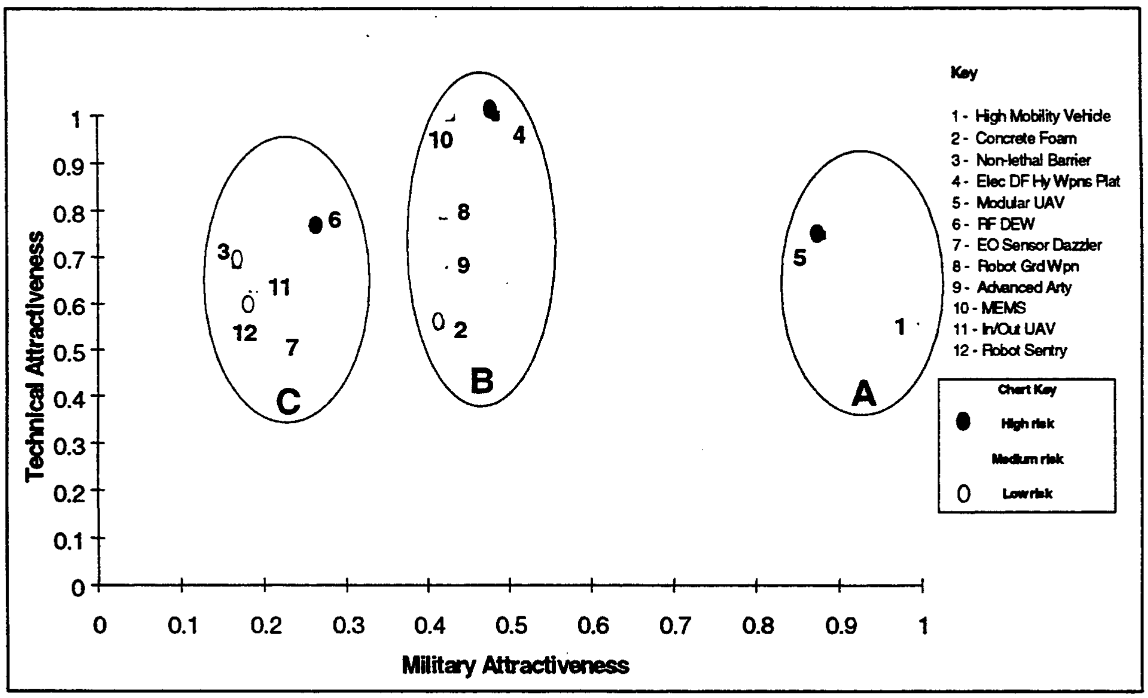


Figure 6-5 - Grouping of TSW Systems

- Group A
  - TSW-1 High Mobility Vehicle.
  - TSW-5 Modular UAV.
- Group B
  - TSW-4 Electric Direct Fire Heavy Weapons Platform;
  - TSW-10 MEMS;
  - TSW-8 Unattended Robot Ground Weapon;
  - TSW-9 Advanced Artillery System;
  - TSW-2 Concrete Foam.
- Group C
  - TSW-6 RF DEW Weapon;
  - TSW-3 Non-Lethal Barrier;
  - TSW-7 EO Sensor Dazzler;
  - TSW-11 Indoors/Outdoors UAV;
  - TSW-12 Robot Sentry.

Component technologies: The component technologies of these groups of systems taken from the list of technologies supplied by TM/CSD have been extracted from the data sheets compiled by LS/CSD. The study has assumed, for dis-aggregation purposes that these technologies are mutually exclusive. Subsequent work may wish to address the inter-relationships between the technologies. They were as follows:

- Group A
  - Advanced materials technology;
  - Electric propulsion.
  - Computer applications and information technology;
  - Multi-domain smart sensors;
  - Precision attack;
  - Computing technologies;
  - Communications technology;
  - Nanotechnology;
  - Micro electrical-mechanical systems;
  - Directed energy/RF technology;
  - Man machine interface;
  - Training simulation and synthetic environments.
- Group B (technologies not included above)
  - Electric armaments technology;
  - Data processing, AI, software engineering.

- Group C (technologies not included above)
  - Electronic/information warfare;
  - Electric power generation for the battlefield;
  - Bio-technology;
  - High power laser technology;
  - Smart structures.

Comment: The inherent complexity of the Modular UAV requires a wide range of technologies in order to realise its full potential. Investment, therefore in such a battlefield system indicates that, by doing so, a range of technologies will be available for incorporation into other systems having high military attractiveness. The value of continuing research into those technologies that are specific to systems having low military attractiveness as assessed by this study is, as a corollary, open to question. Any priority listing of technologies needs to be assessed against the cost and risks.

6.3.10 ***Discussion of results***

Military attractiveness

Some members of the teams were more outspoken than others and some articulated their arguments rather better. This could have resulted in other team members being persuaded to a particular point of view or these views being presented as the team opinion rather than as an individual viewpoint. It was not possible to eradicate this element entirely but the chairmen had been carefully chosen and briefed to prevent any undue influence within their teams. In addition to this, at the end of each scenario day players undertook an individual pairwise comparison which would have allowed the exercising of personal opinions, and this was the principal quantitative output.

There were no significant differences between the results of any of the teams or between any of the team member disciplines.

The TSW provided some useful insights into the perceived attractiveness of the candidate battlefield systems and these notes are documented in the full report. The requirement for high levels of information and intelligence in all scenarios is reflected in the consistently high rating achieved by the Modular UAV. It was also noticeable that whilst the High Mobility Vehicle was never the subject for in depth discussion it was highly rated in all scenarios satisfying the underlying need for good mobility on the battlefield irrespective of other systems characteristics.

Of the 12 battlefield systems considered during the gaming phase only the High Mobility Vehicle and the Modular UAV were consistently ranked High in both military and technical attractiveness. When compared against the legacy systems they were also ranked highly, the Modular UAV (TSW-5) ranking slightly higher than the planned AH.

Only TSW-2 Concrete Foam, TSW-3, Non-Lethal Barrier and TSW-6, Advanced Artillery System were not scenario dependent to some degree.

The MEMS concept (TSW-10) was well liked and provoked considerable discussion. There were a number of novel applications put forward and this

system was thought to have both wide battlefield utility and a synergy with other concept and legacy systems.

The Electric Direct Fire Heavy Weapons platform (TSW-4) was extensively discussed both during the team considerations and in the plenary sessions. There was considerable discussion as to the relative merits of a weapon platform of this nature on the battlefield in 2020 and it was generally less well regarded than the AH and other mobility assets. The final pairwise comparison ranked this system well down.

The RF DEW Weapon (TSW-6) was hampered by a perceived lack of mobility, but it was rated highly in its ability to attack AH and as a counter to enemy ISTAR. Overall, an RF capability was perceived to be a very attractive option if it could be delivered accurately. In its current configuration it did not rate highly overall.

The EO Sensor Dazzler (TSW-7) demonstrated better utility in the OOTW scenario than in the higher intensity conflict but possible legal/political objections were raised several times in discussion.

The RF round of the Advanced Artillery System (TSW-9) was thought to have good utility and the Robot Ground Weapon System (TSW-8) was credited with a wide range of roles including that of an aviation minefield.

The Robot Sentry (TSW-12) and the Non-Lethal Barrier (TSW-3) were less well favoured across all scenarios, but there were occasions when their attributes could have made an important contribution to the battle. As a concept, the Non-Lethal Barrier was well regarded but the characteristics as gamed were not well liked.

The Indoors/Outdoors UAV (TSW-11) was thought to have a number of useful applications, especially in the OOTW scenario. Detailed reconnaissance and observation in hostage situations was a favoured role.

6.4 CONCLUSIONS

The primary importance of ISTAR and the need for an effective mobility capability were in the forefront of the players' conclusions. Of the candidate battlefield systems assessed, those valued most highly were modular UAVs able to carry sensor and weapon payloads and a high mobility vehicle capable of a wide variety of roles. These also scored highly for technological attractiveness, although the modular UAV was judged by the panel of technologists to be of high technical risk and the high mobility vehicle of medium risk.

Discussion of firepower tended to emphasise the future importance of reach and speed of response together with the political need to minimise own casualties, casualties to civilians and collateral damage. For example, the military attractiveness of a direct fire heavy weapons platform was strongly questioned due to its lack of mobility and range of effect. Excluding MEMS, the attractiveness of unattended robots, especially left in enemy territory, was reduced because of concern about vulnerability. Precision artillery was considered to have good utility.

The potential of RF weapons was highly rated, but it was not clear whether in practice this particular manifestation of a system would be able to address a wide enough range of tasks (e.g. counter-communications, counter-STA and counter-missile), and have the necessary mobility and be small enough not to be overly vulnerable. These types of systems tend to be of medium to high technical cost and risk.

The Electric Direct Fire Heavy Weapons Platform is likely to be high to very high cost and risk.

A major technological, cost and risk driver for the future battlefield was the requirement for pulsed power energy sources of a practicable size, weight and performance.

The Non-Lethal Barrier and Concrete Foam raised concerns about the ability to employ them in a timely manner as part of a NATO force which is likely, in many scenarios, to be advancing rapidly. Although assessed to be of low technical risk and cost, their military attractiveness was also judged to be fairly low.

The battlefield systems were ranked for their military attractiveness by the players in the following groups:

- Group A
  - TSW-1 High Mobility Vehicle;
  - TSW-5 Modular UAV;
- Group B
  - TSW-4 Electric Direct Fire Heavy Weapons Platform;
  - TSW-10 MEMS;
  - TSW-8 Unattended Robot Ground Weapon;
  - TSW-9 Advanced Artillery System;
  - TSW-2 Concrete Foam;
- Group C
  - TSW-6 RF DEW Weapon;
  - TSW-3 Non-Lethal Barrier;
  - TSW-7 EO Sensor Dazzler;
  - TSW-11 Indoors/Outdoors UAV;
  - TSW-12 Robot Sentry;

Component technologies: The component technologies of these groups of systems taken from the NATO Study Top Ten list are as follows (Note: The technologies within each group are not in priority order):

- Group A
  - Advanced materials technology;
  - Electric propulsion.
  - Computer applications and information technology;
  - Multi-domain smart sensors;
  - Precision attack;
  - Computing technologies;
  - Communications technology;

- Nanotechnology;
- Micro electrical-mechanical systems;
- Directed energy/RF technology;
- Manoeuvre machine interface;
- Training simulation and synthetic environments.

- Group B (technologies not included above)
  - Electric armaments technology;
  - Data processing, AI, software engineering.

- Group C (technologies not included above)
  - Electronic/information warfare;
  - Electric power generation for the battlefield;
  - Bio-technology;
  - High power laser technology;
  - Smart structures.

The inherent complexity of the Modular UAV requires a wide range of technologies in order to realise its full potential. Investment, therefore in such a battlefield system indicates that, by doing so, a range of technologies will be available for incorporation into other systems having high military attractiveness. The value of continuing research into those technologies that are specific to systems having low military attractiveness as assessed by this study is, as a corollary, open to question.

6.5 POST ANALYSIS - RESEARCH INVESTMENT DECISIONS

6.5.1 Introduction

It is suggested in the main report that, in addition to the composite measures of technology attractiveness and military attractiveness, follow-on work be undertaken to illustrate how the information on cost and risk of the concepts could be used to provide guidance on research investment decisions for the particular concepts used in the TSW.

6.5.2 Criteria

The first step is to identify key criteria that influence funding decisions for the TSW concepts. It is suggested these are:

a. the contribution of concepts to increasing military effectiveness,

b. the likelihood of successfully completing the research, proving the concept and achieving an ISD of 2020, which is normally expressed in terms of the technical risk,

c. the estimated cost of the research programme to completion and the estimated capital cost of the fielded equipment.

6.5.3 ***Illustrative Results and Discussion***

Figure 6-6 shows technical risk plotted against cost of research for the TSW concepts, using the data on technical risk and cost from Table 4 of the main report. The levels of risk reflect the judgements made by the panel of technologists, with the Electric Tank classified as very high risk by general consent. The categories of risk used are therefore: very high, high, medium and low risk. Bands of risk have been used in Figures 6-6 and a further judgement has been made to place the TSW concepts in relative positions within each band. Figure 6-6 shows the Electric Tank is very high risk and cost and it is very unlikely to be fielded in 2020. Conversely, TSW 2, the Concrete Foam concept, and TSW 3, the non-lethal barrier and TSW 12, the Robot Sentry, are low risk and therefore do not constitute suitable long term funded programmes for LO2020. However, the Robot Sentry could be medium risk if the concept is taken to its full potential.

The military attractiveness, (estimated military effectiveness) of the 12 TSW concepts is shown in Figure 6-7. The TSW Concepts are placed along the x axis in descending order of military attractiveness, with the highest on the left hand side (on the y axis), consistent with the order given in the Conclusions of the main report. The points are joined together to make it easier to see trends. Obviously there is a minimum military payoff below which it is inappropriate to fund research. For the purposes of LO2020 it is suggested that any concept with a relative score of 0.2, or below, for military attractiveness (1.0 is the maximum score) should not be funded and this threshold level is shown on Figure 6-7. The concepts with very high and very low technical risk are also highlighted in Figure 6-7 by designating them VHR and VLR respectively. This suggests that no long-term research investment should be made for TSW 12 (Robot Sentry) and there is a marginal case for funding TSW11 (Indoors/Outdoors UAV), TSW 7 (EO Sensor Dazzler) and TSW 3 (Non-Lethal Barrier).

During the structured discussions in the TSW, considerable interest was shown in the novel soft kill weapons of DEW lasers and RF weapons, but they scored lower than conventional hard kill systems and ISTAR assets. However, because of their novel nature and their potential wide utility across the spectrum of conflict, it is suggested that work on the EO Laser Dazzler, TSW7, and for RF Weapon TSW6 should be funded

It is suggested that the funding for the electric tank be confined to enabling technology research to address the high risk area of heavy duty pulsed power. Figure 7 shows the funding recommendations for systems and enabling research for the range of TSW concepts considered. Obviously the correct balance has to be struck between the funding for enabling technologies and for system technologies.

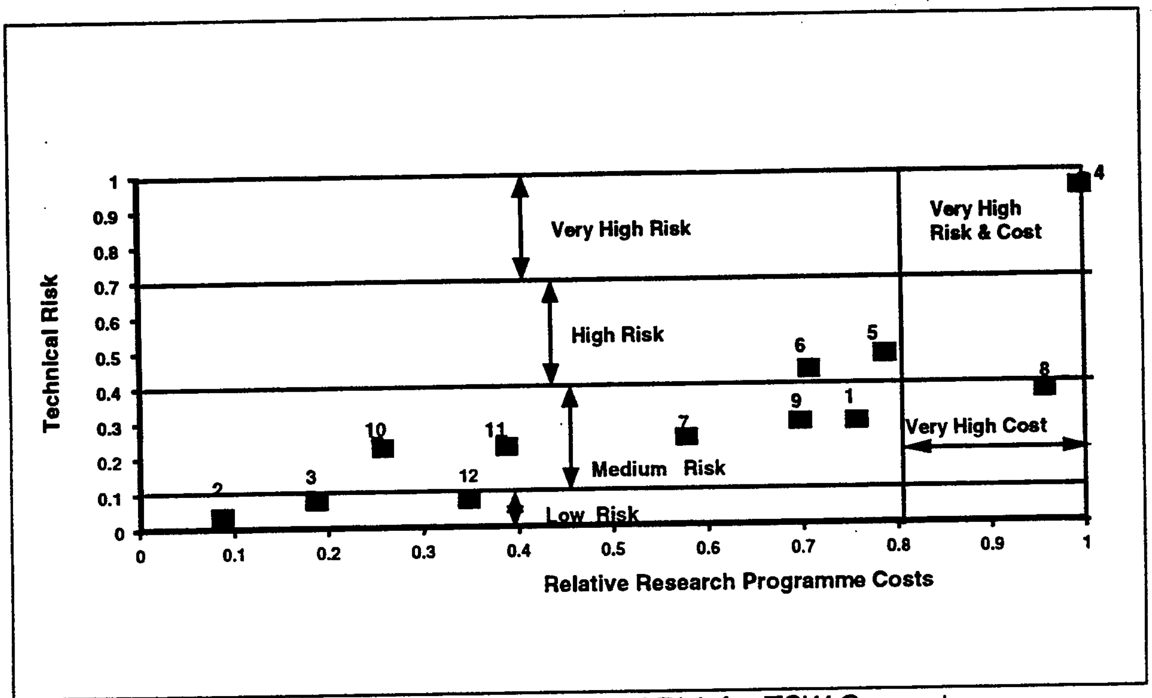


Figure 6-6 - Relative Cost & Technical Risk for TSW Concepts

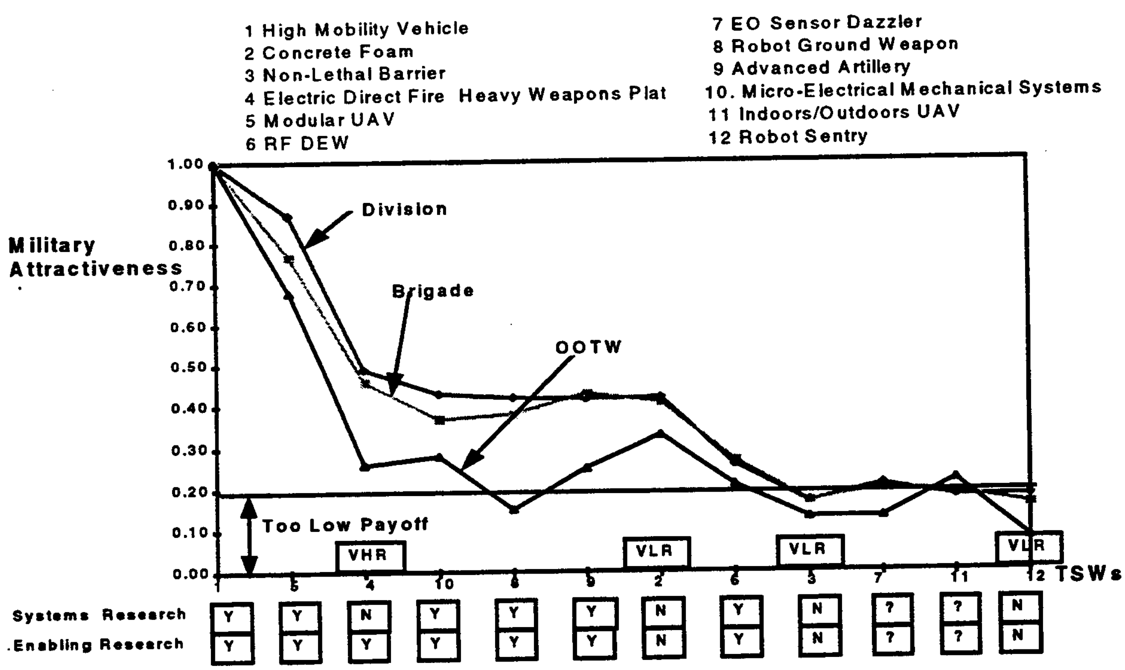


Figure 6-7- Military Attractiveness for TSW Concepts for 3 Scenarios

Note: Funding recommendations for systems and enabling research for the 12 TSW concepts are shown above in Figure 6-7 by the boxes: Y for Yes and N for No funding.

6.5.4 **Conclusions**

The plot of technical risk against the cost of research provides an effective means of identifying the high-risk concepts which should only be funded at systems level if they offer high military payoff. It also identifies the low risk concepts that are therefore short term and not part of a long-term programme.

The plot of military attractiveness shows those concepts offering low potential military pay off with a relative score of 0.2 or below, where the maximum is 1.0.

The combination of Figures 6-6 & 6-7 provides a reasonable guideline on the relative merits of investing in research programmes for the TSW options. The recommendations for funding the concepts are shown in Figure 6-7. The results are illustrative and apply only to the specific TSW concepts and not to their generic areas.

6.5.5 **Recommendations**

The recommendations concerning funding research programmes in support of the specific TSW concepts are given in Table 6-5 below. Where there is significant military payoff but very high technical risk, such as for the Electro-Magnetic Gun (TSW4), then a lower level of funding is appropriate to address the high risk of the concept decisive technologies. No long term funding is appropriate for the low risk concepts, TSW 2, 3 &12 since they could be funded as short term programmes, although TSW 3 & 12 are judged to have low military payoff. Significant funding is justified for the High Mobility Modular Vehicle (TSW1) and the Modular UAV (TSW 5). As mentioned previously, TSW 10, 8, & 9 should be funded and there is a case for funding the DEW concepts since they are new capabilities with wide utility for Sea, Land and Air applications.

System	Title	Systems research	Enabling Technology	Risk	Cost	Relative Military Pay-off
TSW-1	High Mobility Vehicle	Yes	Yes	M	MH	H
TSW-2	Concrete Foam	No	No	L	L	M
TSW-3	Non-Lethal Barrier	.No	No	L	L	L
TSW-4	Electric Direct Fire Hy Wpns Platform	No	Yes	VH	H	M
TSW-5	Modular UAV	Yes	Yes	H	MH	H
TSW-6	RF Directed Energy Weapon	Yes	Yes	H	MH	M
TSW-7	EO Sensor Dazzler	Yes	Yes	M	M	M*
TSW-8	Unattended Robot Ground Wpn	Yes	Yes	M	H	M
TSW-9	Advanced Arty System	Yes	Yes	M	MH	M
TSW-10	Micro Electrical Mechanical Systems (MEMS)	Yes	Yes	M	ML	M
TSW-11	Indoors/Outdoors UAV	No	No	M	ML	L
TSW-12	Robot Sentry	No	No	L	ML	L

Table 6-5 - Funding Proposals for the TSW Concepts

7. ANNEX VII -SUMMARY OF COMPARISON STUDY BETWEEN TECHNOLOGIES OF LO 2020 AND MARITIME OPERATIONS (MO) 2015

7.1 BACKGROUND

When comparing technologies used by different military services, a comparison of land and maritime forces technologies of the future must first take into consideration the disparate elements inherent between the different services. For example, new ship, naval aircraft, or underwater detection system designs would not appear to be applicable to future land force operations. For this reason, the following summary and attached matrix compares only the LO 2020 study with the MO2015 "C3I" study, i.e., Command, Control, Coordination, and Intelligence, and avoids other Functional Warfare Areas such as Surface and Anti-Submarine Warfare, or Carrier Air Power Projections. MO2015, C3I contained references to advanced technologies that wholly, or in part, are compatible with NATO land force technologies needed to take these forces into the next century. According to MO2015, "technical development will be used to provide quality forces at less expense; longer life platforms; lower through life costs and in some cases lower specifications."

7.2 FOCUS

This summary does not attempt to repeat the MO2015 study but simply tries to identify some future technologies that are similar to technologies highlighted in the LO 2020 study. By sharing the technologies and/or costs of development, NATO would realize substantial savings by avoiding duplication of effort and taking advantage of economies of scale. This cooperation would also help ensure that future C3I systems are compatible across national and service lines. Lastly, the summary identifies C3I technologies presented in MO2015 not specifically mentioned in the LO 2020, which may also have applications to land operations.

7.3 COMMAND AND INFORMATION SYSTEMS AND ARCHITECTURES

At the heart of the MO2015 study is the reality that Naval Commanders at all levels from each service must have access to sufficient information on which to base political and military decisions. The primary focus of the study was the development of effective, compatible and secure C3I systems that provide commanders, at all levels, with an accurate and up-to-date "picture" of the battlespace. MO2015 discussed the absolute need for new information systems architecture, design, hardware, protocols, software, and multi-level security features to accomplish this goal. There are huge amounts of information available from a variety of sources and databases. The systems must be designed to not overload the commander with all information available but rather that information necessary for good situational awareness on which to base decisions. For example, the captain of a ship probably does not have the need, time or resources to accept and process the volumes of information essential to an Officer in Tactical Command (OTC). As stated in this study, "It is the availability, completeness and correctness of information and the rate at which it can be used that is important."

7.4 COMMUNICATIONS

Perhaps as important to the effectiveness of the C3I function of Information management is the ability of the commanders to quickly and securely communicate to other services and commands. The advantages gained over the enemy through advance Information gathering and distribution technology are diminished without an equal ability for compatible, timely, and secure communications among a variety of allied forces. Communications within the "military information highway" will include voice, messages, data, graphics, images, video, and faxes, and be transmitted at various levels of security. Advances have been made in fixed communications systems and include new technologies such as, beyond-line of sight (BLOS) and non-LOS (NLOS), satellite communications (SATCOM), photonic and fibre optic, signal processing, meteor burst, surface wave (or non-line of sight), ionospheric reflection (HF), and sensitive reception technology. However, for the mobile (tactical) user, there have been no significant technological breakthroughs and only small, incremental changes are expected in the future. MO2015 listed numerous shortfalls that include: Lack of cross-nation common standards and equipment; lack of video conferencing capability; inadequate satcoms; sufficient comms for naval forces but insufficient comms more mobile forces, i.e., land and air forces; current HF capacity is inadequate fall-back for satcoms; lack of secure frequency comms, not all nations' reconnaissance assets have exchange data efficiency, and fax terminals not fitted to many ships.

7.5 COMPUTER HARDWARE, SOFTWARE, AND PROTOCOLS

Related to both Information Systems design and Communications are the purchase of increasingly powerful computer hardware and the development of new software and protocols. These developments are necessary to facilitate the gathering, collating, and distribution of intelligence while maintaining security and preventing the enemy to use "information warfare' technologies to corrupt or defeat these systems. MO2015 highlighted several "shortfalls" which include: Lack of automated systems for storing, filing, and sorting information; lack of interoperable terminal equipment; high volume, low capacity to interpret information; lack of capture, preparation, and presentation facilities for text and graphics; lack of automated image storage, processing and analysis equipment; lack of compatibility standards within and among various systems; and, inadequate protection/security from outside disruption.

7.6 MISCELLANEOUS TECHNOLOGIES

MO2015 discussed other technologies, which should have equal potential for land forces. These include: High sensitivity communications technology; Helmet/Platform displays; Encryption; Identification, Friend or Foe (IFF); Radio Frequency (RF) and Acoustic Communication Design; Sonar, Electrical, Laser, Infrared (IR), and Ultra-Violet (UV) Sensor Systems; and, Video Servers.

7.7 OTHER TECHNOLOGIES

MO2015 also discussed several other technologies, which were not included as one of the general technology categories in LO 2020 but which may be relevant to land operations. These technologies include: Fax capability, Message Handling facilities and equipment standardization, Use of Comsatcom and Milsatcom, and Optical Communications.

7.8 CONCLUSIONS

MO2015 is an excellent guide to advanced C3I technologies intended for use by future NATO Naval Forces. Some of the technologies, e.g., information and communication technology, are currently being studied by land forces and will be adopted by land forces of the future. These "vital" technologies must be compatible with similar systems of other member countries and services in order to conduct joint operations. Finally, many of the "other" technologies cited above can be adapted for use by land forces.

Notes:

Possible new areas to consider: Fax capability, message handling facilities/equipment standardization, use of COMSATCOM and MILSATCOM, optical communication.

8. ANNEX VIII -SUMMARY OF COMPARISON STUDY BETWEEN TECHNOLOGIES OF LO 2020 AND AEROSPACE 2020

8.1 BACKGROUND

At first glance, comparing the future technologies used for land operations with technological developments of future air and space operations may seem incompatible. There are some developing aerospace technologies, which do not appear to have relevance to land operations, e.g., hypersonic propulsion systems or aircraft design considerations. However, the Aerospace 2020 study contains many references to advanced technologies that wholly, or in part, are compatible with technologies needed to take NATO land forces into the next century.

8.2 FOCUS

This summary does not repeat the Aerospace 2020 study but rather attempts to identify some of the future technologies in the study that are similar to technologies outlined in the LO 2020 study. By sharing the technologies and/or costs of development, NATO would realize substantial savings by avoiding duplication of effort and taking advantage of economies of scale. This cooperation would also help ensure that future communications and weapons systems are compatible across national and service lines. Lastly, the summary identifies technologies presented in Aerospace 2020 not specifically mentioned in the LO 2020, which may also have applications to land operations.

8.3 INFORMATION SYSTEMS

One of the most important technologies discussed in Aerospace 2020 and one which cuts across all national and individual service lines is information technology. The incredible pace of development of computer hardware and software in the last few years will certainly continue, and even accelerate, in the future. Aerospace 2020 discussed the absolute need for new information systems architecture, design, hardware, protocols, software, and multi-level security features. With the exception of some very esoteric weapons platform technologies, the primary focus of the study was the development of effective, compatible and secure C4I systems that provide commanders, at all levels, with an accurate and up-to-date "picture" of the battlespace. There are huge amounts of information available from a variety of sources and databases. The systems should be designed to not overload the commander with all information available but rather that information necessary for good situational awareness on which to base decisions. For example, a company commander does not have the need, time or resources to accept and process the additional information, which might be essential for an army corp commander. As stated in the study, "the technological challenges of command and control begin with the acquisition of data and proceed through the processing of information, its movement and dissemination, and its presentation in a suitable form to the (appropriate) user."

8.4 COMMUNICATIONS

Perhaps equally as important as information technologies, are advanced communications technologies. Aerospace 2020 discussed at length the "vital aspect" of communicating information to the various command structures. Communications within the "military information highway" will include voice, messages, data, graphics, images, video, and faxes, and be transmitted at various levels of security. Advances have been made in fixed communications systems and include new technologies such as, beyond-line of sight (BLOS) and non-LOS (NLOS), satellite communications (SATCOM), photonic and fibre optic, signal processing, meteor burst, surface wave (or non-line of sight), ionospheric reflection (HF), and sensitive reception technology. However, for the mobile (tactical) user there have been no significant technological breakthroughs and only small, incremental changes are expected in the future. Traditional radio frequency (RF), i.e., FM, UHF, VHF, EHF, and upper HF, wireless communications will remain the mainstay for tactical units. These systems will continue to be susceptible to natural, and "man-made" disruptions and limitations, e.g., electronic counter-measures (ECM) and electronic counter-counter-measures (ECCM).

8.5 SENSORS

Tying into the above information and communications systems, the study discussed at length the various current and advanced sensor systems needed to provide the commander with the "situational awareness" necessary on which to base sound tactical decisions. Current multispectral sensing systems include passive and active, acoustic, electro-optical (IR, UV, Visible Wave), radar, infrared (IR) and lasers. These "collection" systems must also include sensor information correlation and fusion systems. By 2020, these systems should be available at medium ranges and near real time. Three of the most promising sensor developments are Synthetic Aperture Radar (SAR), Microwave Radiometry, and Multispectral/Hyperspectral Radar. With the continued improvement and fielding of stealthy platforms, new, more advanced (sensitive) sensors will need to be developed. One such system, still in the "experimental, proof-of-concept" phase, is the ultra-wideband (UWB). The advantage to a UWB system is its ability to penetrate layers of camouflage, such as foliage, earth, or man-made, non-metallic structures.

8.6 DIRECTED ENERGY WEAPONS

Aerospace 2020 discussed at length Directed Energy Weapons (DEW) and predicted that DEW systems will "evolve into commonly used weaponry by 2020." Under the category of DEW's, the study included Electromagnetic Pulse and Ultra-Wide Band Pulse, RF Warheads, Laser systems. The Electromagnetic and Wide Band Pulse systems included high-power microwaves, magnetrons, klystrons, and longer-term developments, such as a "Super-Reltron" tube, which attempts to marry the high-power attributes of the klystron with the size and efficiency of the magnetron. The study envisioned RF Warheads replacing conventional missile or artillery warheads against targets whose electronic circuits are vulnerable if engaged at a "short distance." The laser systems

discussed included High-Energy Lasers (HEL) and Low Power Lasers and predicted major breakthroughs in HEL technology over the next 25 years.

8.7 INFORMATION WARFARE TECHNOLOGY

Information is power and future commanders with access to timely information from a variety of sources will have a decided advantage over their adversary. Unfortunately, this increased reliance on information technology can quickly turn to a disadvantage if the enemy has the ability to access the same system. Aerospace 2020 predicted that information warfare would assume increased importance in the next decades. The U.S. General Accounting Office estimated that over 150,000 successful attacks were made against the Department of Defense computer systems in 1995. Recent news articles have demonstrated that determined "hackers" with relatively modest resources have the capability to disrupt protected information systems. The development of Information Warfare involves two related aspects: digital attack upon computer information systems and techniques for resisting such attacks. Some of the "offensive" measures identified by the study include: malicious software code, deliberately engineered chip hardware vulnerabilities, exploitation of software vulnerabilities, non-nuclear EMP weapons, silicon-eating biological weapons, cryptography and cryptanalysis, deception and authentication, and psychological operations. "Defensive" measures to counter such an attack might include authentication, access control, confidentiality, data integrity, and "non-repudiation" software. "Such security architectures should provide technical protection, with the limitation that they cannot protect against problems arising from captured equipment or unfaithful personnel."

8.8 MISCELLANEOUS TECHNOLOGIES

Aerospace 2020 discussed other technologies, which should have equal potential for land forces. These include: conversion of solar energy to electricity, new designs and displays for helmets, improved electrical batteries, holography and 3-D images, identification, friend or foe (IFF), inertial navigation and global positioning (GPS) systems, microsensors for control of structures, and video systems.

8.9 OTHER TECHNOLOGIES

The study also discussed several other technologies, which were included as one of the general LO, 2020 technology categories but may be relevant to land operations. These include: virtual development, testing, evaluation, and production; military/civil dual use technologies; human-machine interface; synthetic environments; "psychophysiologically" augmented cockpits; alternative controls (aircraft and vehicles); robotics; and voice/natural language recognition.

8.10 CONCLUSIONS

Aerospace 2020 is an excellent guide to advanced technologies intended for use by future Air Forces. Some of the technologies, e.g., information and communication technology, are currently being studied by land forces and will be adopted by land forces of the future. These "vital" technologies must be compatible with similar systems of other member countries and services in order to conduct joint operations. Additionally, many of the other technologies cited in the study can be adapted for use by land forces.

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Information systems	War games
Force structure planning	Weapon systems
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14. Abstract

This is the final report of the Long-Term Scientific Study on Land Forces in the Year 2020. This study identified the types of land forces and their capabilities and characteristics that will be required on the NATO battlefield in the year 2020 for warfighting and other military operations. This information provides SHAPE, and subsequently the major NATO Commanders, with a basis for long-term requirements and defence planning guidance.

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